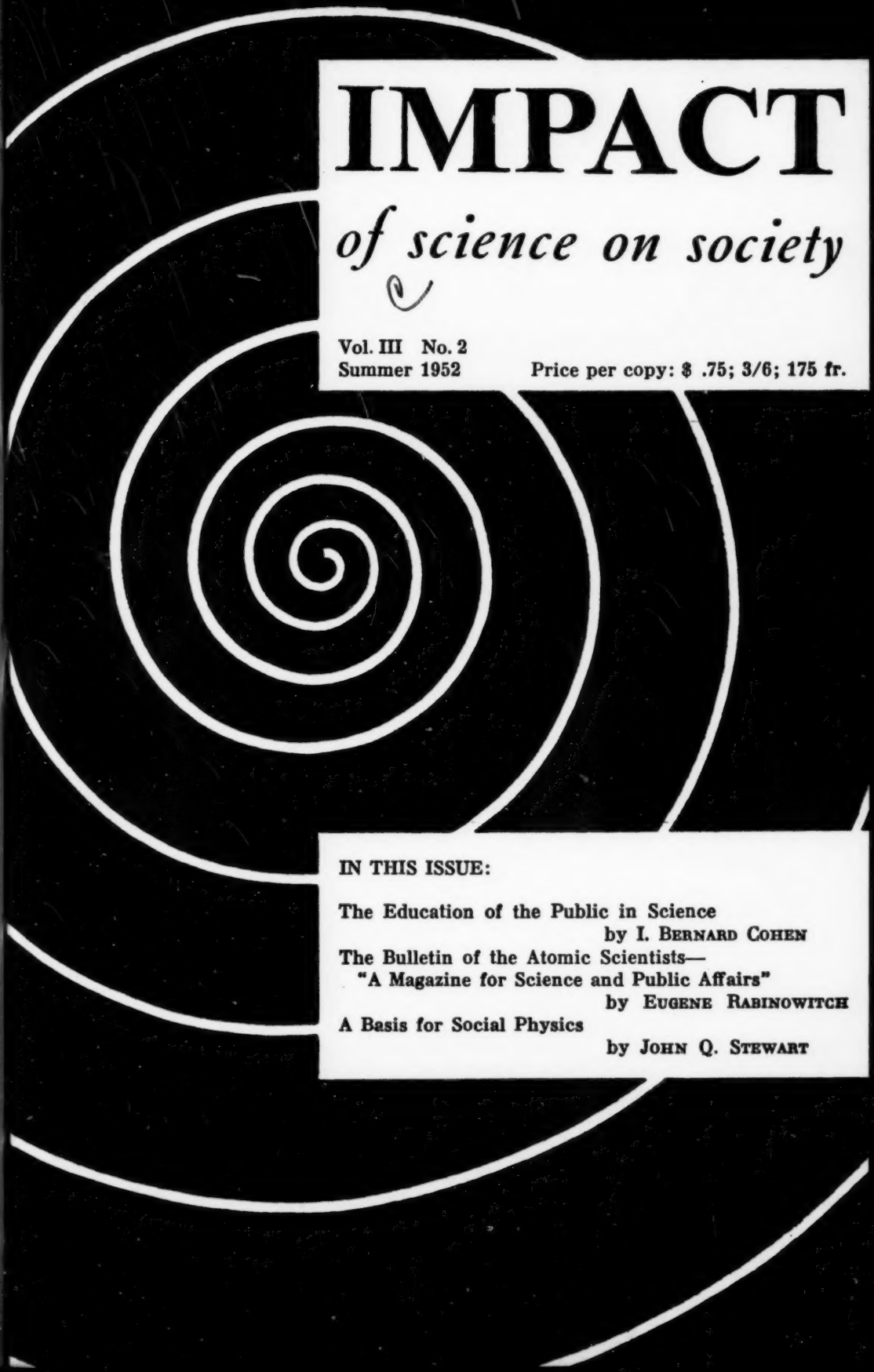
IMPACT

of science on society

Vol. III No. 2
Summer 1952

Price per copy: $ .75; 3/6; 175 fr.



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by I. BERNARD COHEN

The Bulletin of the Atomic Scientists—
"A Magazine for Science and Public Affairs"
by EUGENE RABINOWITCH

A Basis for Social Physics
by JOHN Q. STEWART

IMPACT *of Science on Society*
quarterly

Annual subscription:
$2.50; 12/6; 600 fr.

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IN THIS ISSUE

The education of the public in the understanding of science is a necessity for all intelligent citizens throughout the world who live in a scientific age and whose thinking constitutes "public opinion". In every democracy, the public governs the support of science and the use of its achievements. Modern means of mass communication give ample information about science but contribute little to its understanding. In this issue, Dr. I. Bernard Cohen, of Harvard University, discusses this problem in the light of his experience in teaching science to non-science students. It is frankly American experience. The editors hope to publish similar discussions from other countries in forthcoming issues. The present article is based on the physical sciences, although Dr. Cohen himself thinks that the biological sciences have more to offer the student than the physical sciences, and that biology leads naturally to the study of group and individual human behaviour.

In the long run it will prove valuable to teach "understanding of science" in underdeveloped areas, even though the most immediate need will seem to be for technical education. Such areas will need applied research of a high order, which will flourish in any area only if pure, fundamental research also flourishes; hence, there is a need for a general understanding of science on the part of the population as a whole.

The article by Dr. E. Rabinowitch on the American monthly that carries the sub-title "A Magazine for Science and Public Affairs" was invited by the Editors because the organization of the Atomic Scientists in America, and the publication of their bulletin, expressed an unprecedented surge of conscience on the part of scientists and a valiant effort to direct the thinking of the intelligent public to an understanding of the vast future consequences of atomic energy.

It is the belief of many physical and social scientists that the social sciences must and will develop toward the status of exact sciences. But how this will be done is not clear. Professor John Q. Stewart describes one approach. His work has attracted much attention and has even been caricatured as leading to the control of social masses by savants who need only to push buttons to evoke what they desire in social response. Dr. Stewart is much more modest—and scientific—and in this issue presents merely a "basis" for a physics of society.

The Editors.

THE EDUCATION OF THE PUBLIC IN SCIENCE

by

I. Bernard Cohen

The writer is Assistant Professor of the History of Science and of General Education at Harvard University, and Managing Editor of Isis, *the quarterly journal of the History of Science Society. He is the author of* Science, Servant of Man, *Little, Brown, Boston, 1948, and Sigma Books, London, 1949;* Some Early Tools of American Science, *Harvard University Press, Cambridge, Mass., and Oxford University Press, London, 1950; and of several other works including (in collaboration with Fletcher G. Watson)* General Education in Science, *Harvard University Press, Cambridge, Mass., and Oxford University Press, London, 1952.*

In the following pages, an investigation will be made of education in science and of the meaning of progress in relation to science.

I may be permitted to anticipate the argument to the extent of making clear at once that I do not believe that all the world's ills may be cured by science, any more than I believe that the world's ills are attributable to science. Yet, to the extent that progress has a meaning for the world in terms of science, in our educational systems today we need science instruction of a wholly new kind for those who have no choice but to be citizens in a "scientific age". More thought has been given in recent years to the college student non-scientist than to the non-scientist on lower levels of education or the non-scientist whose college career is a thing of the past. It is my firm conviction that the success of the new education in science on the college level teaches us important lessons for the better education of non-scientists in general. Hence, in addition to an exposition of some recent trends in science instruction at the college level, and a brief exposition of the history of science instruction in its social context, the present study will discuss positive recommendations for a wider diffusion of an understanding of science.

THE SUPPORT OF SCIENCE

Among the exciting aspects of science which have tended to produce awareness of it as a force affecting our lives may be mentioned: the atom bomb with its frightening implications,

nuclear power with its promise of a wholly different technology from any we have known, the hopeful warfare against disease, the full use of the natural resources of the earth, the production of a maximum amount of food and clothing, and the possibility of interplanetary travel. The social nature of the problem of science and the non-scientific public does not arise only from the magnitude of such effects of science as we see around us at present and envisage in the foreseeable future, but also from the general realization that the future of science itself may depend to an ever-increasing degree on the public mind.

The reason for the latter arises directly from the economic trends of our time. There have been until now only a few types of support given to science including that of (a) industry; (b) government; (c) universities; (d) private institutions of research set up by a single individual, groups of individuals, or a wealthy family. These sources have often overlapped. For instance, in the United States many of the universities and colleges are supported by state or municipal governments, but find additional research funds in gifts or bequests from individuals, in grants from the federal government, from industry, or from foundations (established by private capital); their income may come in part from the state or municipal government, in part from tuition fees and in part from private endowment. [1][1] So, too, those that are supported by private endowment receive large research grants from the federal government, from industry, from foundations, and from local governments. In Europe the privately endowed university is less common than in America, and the support comes from the state even if, as in some of our state universities in America, there may be some private endowment as well.

In America, where the privately-endowed university has been most conspicuous, the shift towards state support of science has been increasing during the last decades at what has seemed to many responsible individuals to be an alarming rate. Scientific research today has become more and more expensive, requiring for each senior scientist a corps of assistants, secretaries, computers, machinists, to say nothing of complicated and expensive machinery and experimental apparatus. At the same time that research itself has been becoming more and more costly, the private sources of support have been drying up. The combination of these two factors has caused a rapidly increasing portion of the scientific research in our universities to be financed by government. In a country like America, this means that scientific research must continue to demand growing support from the taxpayers, as has been the case in most European countries; although the situation is not wholly identical in Socialist or Communist countries, the fact remains that a portion of the national income is everywhere being set aside by national governments for the "public" support of science.

One reason for the present willingness of governments to spend

1. The figures in brackets refer to the bibliography at the end of this article.

such large sums of money for scientific research is the demonstration during the late war that scientific reseach of all sorts has important and immediate bearings on national security. Surprise was general at the abstract branches of scientific research which proved to have contained the seeds for important military developments. Today no one is willing to state that any field of exact knowledge may be devoid of potentialities that will either make attacks more powerful or defences more sure.

The world will not, we trust, live forever on a military economy. A fundamental problem for society, therefore, is whether it will continue, during the peace that we envisage in the future, to support scientific research of every sort on the scale which has become normal during the present period of tension. It is easy enough to make out a case for peacetime support of so-called medical research. So long as cancer is the scourge of mankind, no one will doubt the value of expending whatever sums may be necessary for research into problems of growth and others that seem related to the cancer question. Nor would any one hesitate for a moment to encourage research directly related to making agriculture more productive, to lengthening the span of life of human beings and animals, and so on.

But where shall we find justification for the construction of giant observatories which seek out distant stars, galaxies, and globular clusters which are so very far away from us that the light by which we study them takes millions of millions of years to arrive at the earth? Indeed, may we not ask whether, by the time this light reaches us, those very astronomical bodies or systems have ceased to exist: not recently, but perhaps millions of years ago? The world needs more housing, more clothing, more food—how can we justify the satisfaction of what must seem to the uneducated an idle curiosity about what is going on in the great beyond, while the practical needs of man loom so strongly before us?

The foregoing example—extreme as it is—will show how dangerous for the progress of science is a simple equation of scientific research with practical affairs and a plea for the support of science based on its immediate usefulness alone. In other words, however much we may esteem (or even, in some cases, regret) the vast applications of science, we must not—if we wish the scientific enterprise to continue—plead for its support solely on the basis of the immediate tangible by-products. We shall see in a moment that there are values in science, apart from practical applications, that fully merit public support and esteem.

EMPIRICAL SCIENCE AND APPLIED SCIENCE IN HISTORICAL PERSPECTIVE

Before seeking possible justifications for the public support of scientific research, we must understand what science is and what it isn't, what it does and what it doesn't. I will not attempt to define science, but will state a fundamental proposition to which the

scientific enterprise as a whole seems to be dedicated. It is:

There is a kind of objective reality to the world around us which may be ordered in terms of theoretical concepts organized into conceptual schemes, and given a consistent explanation which agrees with the specialized kind of experience provided by experiment and controlled observation, and which leads to predictions which may be verified on the level of that experience.

An important corollary to this proposition is:

As our understanding of the external world increases, so our control of nature becomes deeper, surer and more far-reaching.

If there is any one factor that differentiates what we call "modern science" from what may be considered the equivalent of "science" in Antiquity and the Middle Ages, it is a recognition of the truth of this corollary—perhaps even more than that of the proposition itself. During the seventeenth century, the time that we associate with the first high point of the "scientific revolution" in the modern sense, this fundamental truth was often eloquently repeated—as by Lord Bacon in England and Descartes in France, in his famous *Discourse on Method.*

That the corollary follows directly from the proposition is readily seen. A science which deals with the "realities" of the external world as revealed by experiment and controlled observation, and which is characterized by a successful prediction of events in that external world of experiment and observation, provides knowledge that applies to our external environment. Hence, experiment and observation, as Bacon pointed out, lead simultaneously to knowledge and power; "fruits and works", therefore, are the "sponsors and sureties" of science, and "truth and utility are the very same things". Experimental science, unlike metaphysics or pure mathematics, does not begin with an arbitrary set of postulates and deduce their logical consequences; the premises must always be founded in experiential data, so that the conclusions obtained must always apply to the world of experience.

Actually, the science of Antiquity and the Middle Ages was not conceived in wholly abstract terms; for example, ancient astronomy was, in large measure, dedicated to the observation of sun, moon, stars and planets and the attempt to predict their future positions. In the Islamic world in the Middle Ages, in such fields as optics and chemistry, etc., the measure of empiricism and the quality of experiment was high. But the main difference between the old and the new science is none the less in the degree of empiricism, the extent to which there is a conscious drive to limit all speculations about the world around us by the controlled data of experience.

The ideal of a science divorced from experiment or observation and based on imagination and logic is usually associated with Plato, whose influence on the whole of Western thought and education has been far-reaching and is still a potent force amongst us. The late Professor Whitehead went so far as to say that all Western thought is no more than a footnote to Plato. Plato was

actually more interested in the doctrine of ideas, and in problems of the mind and soul or religion and ethics, than in an empirical science based on experiment and observation. He deprecated the vast labours of those who determined the exact length of day and night, the position of the sun and moon, the courses of the planets and stars, and the like. While such studies had obvious practical value, Plato believed that there were higher values in the contemplation of the heavens than in their observation, that the fundamental proposition of astronomy was that the (perfect and immutable) matter of heavenly bodies was different from that of the earth and, therefore, subject to different laws. Like his master Socrates, he distrusted the evidence of the senses and strove to build a science of the soul. Thus, in the *Republic*, we find the statement that the truths of astronomy "are to be apprehended by reason and intelligence, but not by sight". In other words, "in astronomy, as in geometry, we should employ problems, and let the heavens alone if we would approach the subject in the right way . . .".

The poetic character of much of classical Greek science is closely related to the scorn for experiments and applications, and cannot be considered apart from the social situation in which there was a separation between those who produced systems of the mind and those who created objects of practical value. Indeed, the positive achievements of the older science—such as the astronomy of the Babylonians and Hellenistic (or Alexandrian) Greeks, the medicine and biology of such men as Aristotle, Galen, Herophilus and Erasistratus, the optics and chemistry of the Arabs, etc.—was not to be equalled again in Europe until men of learning were once again willing to soil their hands.

In this connexion, we may note the curious paradox to be found in Aristotle, whose biology was based on careful observation but whose physics was not. The modern scholar often uses the phrase, "one of the golden pages of ancient science", in describing Aristotle's defence of observation (and dissection) in biology: a beautiful statement that although the handling of dead animals and plants may seem degrading when compared to a contemplation of the eternal verities of the heavens, yet both must have an equal status in revealing nature to us. The chief reviver of anatomy at the Renaissance, Vesalius, pointed out that no serious advance in the anatomy and physiology of the human body had been made since the time of Galen because of the abandonment of the practice of dissection by medical men and scientists themselves, owing to the contempt which they held as free-born men for disagreeable manual tasks. "The art of medicine went to ruin," he declared, when "the more fashionable doctors in Italy, in imitation of the old Romans, despising the work of the hands, began to delegate to slaves the manual attentions they deemed necessary for their patients. . . . When the whole conduct of manual operations was entrusted to barbers, not only did physicians lose the true knowledge of the viscera, but the practice of dissection soon died out, doubtless for the reason that the doctors did not attempt to

operate, while those to whom the manual skill was resigned were too ignorant to read the writings of the teachers of anatomy." [2]

The aims of the Royal Society of London, founded in the late seventeenth century, reflected the new spirit in science. Boyle and Hooke were among the leaders of the group who saw clearly that the new science based on experiment and observation of nature must, in the sense of Bacon and Descartes, lead to its control. In the eighteenth century, however, despite the many protestations of scientists that their work was to be useful, the effect of science on trades or technology was slight. There was not a single important alteration in the practices of manufacturing or agriculture, mining or even medicine and public health that stemmed from research in pure science. The method of variolation or inoculation, in which an individual was purposefully given a mild case of smallpox as a means of obtaining an immunity, was introduced on a purely empirical basis, and the method of determining longitude at sea, which was perfected at the end of the eighteenth century, depended chiefly on the invention of a better mechanical clock—Harrison, who was responsible for the invention of the marine chronometer, was not a trained scientist.

If we neglect what men said and concentrate our attention on what they did, we cannot escape the conclusion that the present pattern of life—in which every aspect of what we do, eat, wear, manufacture, grow, and use for medication differs from what it was a century ago because of scientific research—is something remarkably new and at most about 100 years old. Only since the middle of the nineteenth century has science begun to fulfil the promise made by Boyle, and then on a scale far greater than even his fertile imagination could have envisioned.

In our own day we have witnessed the great prolongation of life due to the new drugs, and the vast consequences that face us as a result of our having tapped the reservoirs of nuclear energy. The first dramatic example of the far-reaching application of scientific discovery occurred in organic chemistry, following on the heels of young Perkin's attempt to synthesize quinine during a school vacation, which failed of its intent but did produce the first coal-tar dye, mauve. Within a few decades systematic research in organic chemistry—itself a product of the nineteenth century—had produced other new dyes, had synthesized dyes previously obtained only from enormous quantities of plant and animal material, and had made them all available in greater quantities and at lower cost than previously had been the case. The consequences of the new dye industry for science and for mankind were vast and still stagger the imagination. Almost overnight, whole regions which had produced the animal and plant dye materials for centuries were without profitable industry and employment for the inhabitants. Not only did men's dress habits change with the new colours, but the by-products of dye manufacture came in turn to play their part in altering the conditions of life. Some unstable dyes are explosive and the effects of the vast explosive industry are all too well known. Other dyes

have biological or medical uses in staining tissues of various sorts and micro-organisms, and the acceleration given by the new dyes to scientific research in the biological and medical sciences is incalculable. Following that great expansion of organic chemistry applied to the dye industry, there has been a growth of applied science in government laboratories and those established by industry, and the tangible, practical fruits of scientific research have flowed forth in a steady stream until there no longer can be any doubt that an empirically-based science leads simultaneously to an understanding of nature and a control of nature.

Hence there has been a complete reversal of the attitude of both scientist and non-scientist; whereas formerly the scientist in a kind of apologetic mood promised that his work would some day be useful to man, today the scientist finds it necessary to make a strong plea that pure science be not neglected in the enthusiasm for applications. A hundred or so years ago, a large audience was assured for the lecturer on the comet, or on evolution, or on the theory of diffraction; since that time the popularization of science has tended to concentrate more on the latest applications of science or lurid prophecies of the new world science will make. I believe that this phenomenon explains why the foremost scientists of the early nineteenth century were willing to participate in the dissemination of science to non-scientific audiences, and why they have not been willing to do so in the twentieth. For more than three-quarters of a century many scientists have retreated from the public eye, have stressed the aspect of their work that seemed to have no application save the understanding of the world about us, and have defended to each other the ideal of pure science. In a very real sense, they returned to the ancient ideal of abstract and "useless" knowledge.

Archimedes, one of the greatest mathematicians and physical scientists of Antiquity, was renowned in his day for his practical inventions as well as his contributions to pure science, especially for the application of his talents to devices to defend Syracuse against the attack led by Marcellus. Yet, Plutarch tells us, he "possessed so lofty a spirit, so profound a soul, and such a wealth of scientific inquiry, that although he had acquired through his inventions a name and reputation for divine rather than human intelligence, he would not deign to leave behind a single writing on such subjects". He regarded "the business of mechanics and every utilitarian art as ignoble and vulgar", and "he gave his devotion only to those subjects whose elegance and subtlety are untrammelled by the necessities of life". At the end of the nineteenth century, a similar sentiment was widely held. Clerk Maxwell expressed his bitterness after having heard so much about the newly invented telephone, only to discover that the new instrument consisted "of parts, every one of which is familiar to us, and capable of being put together by an amateur". The "disappointment" that he felt "was only partially relieved on finding that it was really able to talk". Rowland, in 1883, lauded pure science and deplored the practice that dignified "telegrams,

electric lights, and such conveniences" by giving them "the name of science". He did not, of course, "wish to underrate the value of all these things; the progress of the world depends on them. . . . So also the cook who invents a new and palatable dish benefits the world to a certain degree; yet we do not dignify him by the name of chemist." [3] Hendrick Antoon Lorentz, known for his theory of electrons and the "relativistic" contraction theory named after him, like Archimedes never left a single written word to indicate the scope of his vast labours in the practical service of his country in planning the reclamation of land from the sea. [4]

EFFECTS OF CHANGES IN SCIENCE ON SCIENTIFIC EDUCATION

Any considerations about science and the public, including scientific education, must take account of the vast changes in the nature and organization of science, particularly with regard to its applications which we have mentioned in the previous section. For much of the literature concerning this subject still presents science as an abstract discipline, or else, concentrates so heavily on the applications that the logic and structure of science is almost totally lost. We must keep in mind that the Platonic ideal of education is still with us to an astonishing degree, just as it dominated the educational thought of the past. Because Plato wrote over the entrance to his academy: "Let no one ignorant of geometry enter here," every secondary school student must still learn the principles of Euclidean plane geometry—although it may be greatly doubted whether the values which educators attach to such study are at all justified by the experience of their students.

In the schools and universities of the seventeenth century, the progress of the new science was somewhat slower than the success of its investigations might have led one to expect. The enemy, Aristotelian or scholastic science, was formidable. The first opponent of the old system to triumph was the science of Descartes, and it is one of the ironies of history that no sooner had Cartesianism become established as the orthodoxy of scientific education, than it in turn was outmoded by the Newtonian physical science which then had to struggle against Cartesianism just as Cartesianism had previously had to struggle against entrenched scholastic and Aristotelian physical science.

In England and America in the early eighteenth century those who learned Newtonian science were "gentlemen", not artisans learning the principles of Newtonian science for any practical reasons. There was, at that time, one major "practical" aspect of learning Newtonian science, although we would not put it in that category today—the theological implications; one cannot read any of the eighteenth century text-books of science in England and America without noting a strong theological basis for science study. As it became increasingly plain that the applications of science were of great importance, and as the primary focus on theological questions began to disappear from the scene when education itself

became more and more secularized, stress began to be laid more and more on practice. Thus, for example, at early nineteenth-century Harvard College, a special course was introduced in "Technology, or the applications of science to the useful arts", under the professorship established by Count Rumford. The founding (by Rumford) of the Royal Institution in London, the Society for the Diffusion of Useful Knowledge, and other societies and mechanics arts institutes provides evidence that in the nineteenth century there was a growing general recognition of the importance of teaching science to artisans who needed practical science in order to become more skilled technicians in the various crafts in which the hand of science was becoming manifest.

The complete victory of experimental and observational science in schools was slower. We know, for instance, that so late as the 1880's in England, a serious protest was made against the introduction of demonstration experiments in British schools. It was held that these would have a bad moral effect upon the students, who should learn to accept their master's word without requiring proof by a demonstration or experiment. [5] By the end of the nineteenth century, however, the victory of science instruction in schools at all levels seemed complete, with experimental and observational science introduced in elementary schools, secondary schools as well as colleges and universities. It is curious to note, however, that the nineteenth century victory has been followed by a dilution. The science requirements of college students, at least in America, have become progressively smaller. For example, Harvard College, like many other American colleges today, demands of all students that they take but one course (two semesters or one academic year) of science. This is the equivalent of about one-sixteenth of the total formal education, and it may be noted that no requirement is made in mathematics. At Harvard, 100 years ago, the requirement was three times as great; about three-sixteenths of the total curriculum had to be spent learning science, one-sixteenth to mathematics and the other two-sixteenths not just to one science as today (the physical sciences *or* the biological sciences) but to several different scientific subjects as well as public health and technology or the applications of science to the useful arts.

In considering the quality of scientific education at the college, *lycée,* or *Gymnasium* level, and in preparatory or secondary schools, we must keep in mind a number of factors. They include, among others, the calibre and training of the teachers, the kind of text-book available, the attitude of the institution toward science or the place of science instruction in the curriculum as a whole, the amount of science taught and the previous preparation of the students in science and in mathematics, the age or maturity of the students receiving the instruction. The quality of the teachers depends on their own preparation, in the end on those who taught *them.* That developments in France at the beginning of the nineteenth century—associated with the great Ecole polytechnique and the Ecole normale—had a decisive influence on science teaching

cannot be denied. First-rank men produced a new kind of teaching, and the text-book designed for their courses were translated and had the effect of raising the level of science instruction everywhere. Another development was the post-graduate school and the doctorate in the sciences, in which the German universities became prominent in the second half of the nineteenth century. As the competence of professors in the sciences in colleges and universities grew, as student laboratories were introduced, and as better text-books became available, science instruction became much better. More and more up-to-date scientific information was imparted. The latter, while laudable, eventually introduced problems of its own, since the attempt to include in one course every aspect of that subject became increasingly difficult, as the increase in scientific discovery was accelerated by the expansion of science. Hence, as today, such courses often attempt to present much more material than most students can digest.

A natural pride in the achievements of science resulted in the inclusion into elementary courses of some applications of science as well as facts and theories. In America, this trend has been specially marked in the public high school where many of the students do not go on to college but enter the world of affairs immediately upon graduation (aged about 18); it is evidently supposed that such practical instruction will appeal to this kind of student and perhaps even prepare him to some degree for skilled work. Often the stress on practical applications is justified by the thesis that we live in a technical age and that students should therefore understand the principles underliying the operation of the gadgets and machines which they will encounter on all sides: the electric bell or buzzer, the telephone, the radio, the television set, the internal combustion engine, the steam engine, the gas turbine, the oxy-acetylene torch, and the applications of nuclear fission. In present-day education, no propaganda is necessary to convince the student that science has practical value. Indeed, the practical applications of science are so omnipresent that many students develop a sort of antipathy to science and prefer to study the social sciences or the humanities.

The times in which we live present new problems for science instruction and I believe that we can best understand the nature of the problem as a whole by considering its operation on a number of different levels.

Let me begin at the highest level—that of the college student (in European countries this will prove to be more the problem of the student in the final years of the *lycée* or *Gymnasium*). For the purposes of this discussion, college students may be divided into two distinct categories: students for whom science instruction is part of professional training, and those for whom it is not. The first category contains students who plan to become engineers, scientists, doctors, and business men who will enter fields of manufacturing, communication, transportation and the like where some knowledge of science is required. The second category includes those students whose professional careers as teachers,

public servants, lawyers, or business men, will never call for specific scientific knowledge or skills—in other words, the non-scientific educated public. I do not know of a single college in the United States—and I believe that the same will hold of the *lycée* and *Gymnasium* abroad—which would permit such individuals to be graduated without some science instruction. The reasons given for such a requirement are often quite unrealistic and, for the most part, based on errors which will be discussed in the following section.

Yet we must note that the needs of students who plan to do further work in the sciences are different from those students for whom the course is a "terminal" one. We must, therefore, examine closely whether a propaedeutic science course has any value for the non-science student, and whether it can provide us with any suggestions that may be valuable in popular education or adult education.

SOME FALLACIES

Some of the traditional reasons for requiring science instruction of all students are based on wholly misleading notions of science and on an unfounded notion of "transfer".

Herbert Spencer claimed a special utility for science in providing a discipline of the mind and maintained that science also offered religious training in that it gave the student faith in immutable relations "in the invariable connexion of cause and effect and in the necessity of good and evil results". [6] But the "transfer" of the "discipline" of one field to another was not accomplished by the students in the way that the nineteenth century educators hoped. A recent investigation of the development of science teaching notes: "Modern physiological and psychological research has shown that the crude doctrine of the formal training of faculties is untenable. It is now realized that memorizing, observing and acts of volition are developed only in connexion with specific ideals, actions and emotions. In order to effect a transfer of training from one department of mental activity to another there must be a linking of the specific ideas, actions and emotions with those of the general mental disposition. This linking is usually brought about by a conscious recognition of the elements common to the different mental activites." [7] A similar thought has been expressed as follows: "Scientific work involves great care to avoid bias, so it is easy for the student to see the need for logical, unbiased thinking in science. However, we should not assume that mere contact with science, which is so critical, will make the student think critically." [8]

In considering traditional errors in the reasons why educators have insisted on science instruction for all students, we shall see that many of the educational fallacies are based on an unwarranted assumption that the student will transfer what he learns in science to his other courses and to every aspect of his life. Would

that it were true, and that the world might become a paradise! Alas, experience answers No and we must seek other ways of bettering the world. Current errors about the benefits of science teaching may conveniently be grouped under five major fallacies, although the reader will note they overlap somewhat.

The Fallacy of Scientific Idolatry

Scientific idolatry consists of believing scientists to be lay saints, priests of truth, and superior beings who devote their lives to a selfless pursuit of higher things. This fallacy has been the subject of attack in a book that has recently had a great popular appeal in America entitled *Science is a Sacred Cow,* by Anthony Standen; a book that has interesting implications for the general problem of science and the public and to which I shall return later on. Typical of the fallacy of scientific idolatry are such statements as:

"The success of the scientific method . . . is based entirely upon absolute honesty of mind and love of truth. . . . Dogmatic prejudice, lying, falsification of facts and data, and wilful fallacious reasoning are all out of harmony with the spirit of the sciences. It is writ large in the history of science that the most heinous offence a man can commit is to falsify his data and let his prejudice and his desires colour his reasoning. It has never been given to such a type of mind to discover any of the important truths of nature. If a student leaves his course in physical science with a typical scientific point of view, he has obtained a moral value which will be a distinct asset and which will help to lead him to a happy and successful life." [9] Again, "Science teaches us how to think straight, how to avoid deceit, and how to benefit mankind most by honouring the authority of Truth." [10] Or "The scientist is a man of integrity and faith who trusts the basic laws of nature and intelligence to lead him into the paths of truth. His loyalty to truth is unquestioned: his capacity for patient and sacrificial inquiry is limited only by his powers of endurance; his devotion to the scientific method is unwavering; his objective is the welfare of mankind; and his discoveries, whether of medicine, mechanics, psychology, or what not, are the free possession of democratic peoples." [11] Any such idolatry of science as a profession nobler than other pursuits, or ennobling, or made up of noble individuals free of prejudice, is not only contrary to all of science as we know it, and therefore a gross misrepresentation, but has plainly little educative value. When students encounter extravagant statements about the character, integrity, high moral purpose, and ideals of scientists, their reaction should be simple healthy derision.

The Fallacy of Critical Thinking

Under this rubric we find such statements as:

"The exercising of critical judgment. . . . This, of course, is the ultimate goal in a science course for non-scientists. The arousing of curiosity and the learning of facts are but means to this vastly

more important end—*the exercising of critical judgment*—a discipline which the student will need the rest of his life. We must have learned from our scientific researches to guess intelligently; after all, to those who make the most intelligent scientific guesses we give Nobel prizes. We encourage the student, in a like manner, to gain confidence in his own intellectual capabilities, so that he himself is willing to make intelligent guesses. In his later life he will be counted upon time and again to make decisions, to make them with confidence, and to make them on a moment's notice. He will have gained practice in just this sort of thing in the science course which I am proposing." [12] Again, "A method of attacking problems that present themselves should be one of the aims of science, both to the individual and to the community. This scientific method and attitude includes a firm belief in realization of *cause* and *effect*. It calls for open-mindedness in a spirit of inquiry. A knowledge of the methods and principles of science to the point of use in ordinary life helps the young person to solve his problems and interpret the world in which he lives. He learns that this world is orderly and dependable. Gradually he is able to interpret it more intelligently and thus to solve his problems and those of the community more successfully." [13]

This fallacy that the study of science teaches students reflective thinking or critical thinking or logical analysis which may then be applied by them to other subjects of study and the conduct of ordinary living may easily be demonstrated by examining carefully the lives of scientists outside the laboratory or study!

The Fallacy of "Scientism"

One of our leading economists has defined "scientism" in the sense, according to French philosophers, in which I will use it here. "We shall," writes Hayek, "wherever we are concerned not with the general spirit of disinterested inquiry but with the slavish imitation of the method and language of science, speak of 'scientism' or the scientistic prejudice." [14] Scientism therefore embraces much that has been written about social problems and the conduct of daily life. Thus methods of trial and error and the exercise of impartial or unprejudiced judgment are, in the fallacy of "scientism", described as applications of science or of the scientific method. Here is an example, from a book addressed to science teachers in the secondary schools: "From the social point of view it is highly desirable that young people should acquire confidence in scientific methods and in their own ability to use them, since they will be called upon, as adults, to choose between different methods of attacking social and economic problems. Such confidence is mainly acquired through young people's own successes in solving actual problems. It may be increased by their being brought to understand how scientific approaches to problems have resulted in impressive achievements." [15] Again, "Training in the rigorous method of science, in so far as the individuals are capable of it, should make for straight and independent thinking on com-

mon economical, social, and political problems in which it is particularly important to submit every idea to rigid scrutiny." [16]

The origin of this fallacy lies in the obvious attempt to attach the value-judgment of science to non-scientific thought. Scientists have obviously been successful in mastering nature's problems; we all would like to be equally successful in solving our personal, social and economic problems; maybe if we ape certain aspects of scientific procedure and call what we are doing "scientific", then we will be successful too—so, it would seem to me, runs the line of "scientism".

The Fallacy of the *Scientific Method*

Somewhere in between the fallacy of scientific idolatry and the fallacy of "scientism", lies the fallacy of *the* scientific method. Here the critical scientist of the mid-twentieth century stands squarely against the tradition of the past century. He recognizes the danger that an oversimplified view of science has presented its achievements in a very misleading way—as if all the great discoveries in science had been the result of the consistent application (without much imagination, thought, or judgment) of a simple set of rules (often six in number) to every situation as it arose. Experience shows, however, that it is easier to see how such rules were supposedly applied after the discovery has been made, than to apply those same rules to the making of actual discoveries. The record of those who have made the important discoveries of the past does not show that they have ever attempted anything such as those who teach *the* scientific method suppose. Science, concludes P. W. Bridman, is nothing else than "doing one's damnedest with one's mind, no holds barred". [17]

I believe that the fallacy of "*the* scientific method", like the fallacy of "scientism", comes from the fact that science has been so obviously (perhaps too obviously) successful in solving its problems, that we have a much wider knowledge of a far greater range of natural phenomena than our ancestors and correlate them under more nearly all-embracing theories, and that along with progress in our understanding of nature has come the increase in our control of nature. The average college senior in physics knows more mathematics and physics than Newton or Archimedes, two of the greatest geniuses that the world has produced.

If the natural scientists are not supermen, and this is something that their fellow faculty members in the social sciences will not usually admit, then their greater success means that they have "something" that the social scientists lack. This "something" is not greater mental ability, so it must be *the* method, that magic key that solves problems just as the philosophers' stone of the medieval alchemists would effect the transmutation of base metals into lead. So the modern search for the philosophers' stone has become the search for *the* scientific method. Since it has been flattering to scientists to be told that they had a superior method, they have not in general argued against this view. Yet if it be true, as I believe,

that the greater success of the natural sciences is due to the simpler nature of the materials with which they deal, the argument fails completely.

Experience simply does not justify the statement that "the citizen who is trained in science may also be expected to exercise his political rights more effectively than one not trained in science, both because of his greater understanding of the nature of the modern world and because of his understanding of the scientific method, the way in which conclusions can be drawn from facts. Understanding of the scientific method confers on him the scientific attitude, which gives him an increased chance of reaching the right decision about political and social questions as well as about scientific questions". [18] Obviously, such a concept as "the right decision" needs clarification of a sort beyond the province of science.

The danger in this fallacy lies in the fact that those who work in the area broadly classified as social science may be led to believe that the success of the natural scientists has been owing entirely to their method. The important aim of understanding and predicting the evolution of society, and perhaps its eventual control, cannot be achieved by the social scientists if they limit themselves to a slavish imitation of the supposed "method" of the physicist. Wolly apart from its danger, the belief in a "cook-book" method denies to the scientific enterprise those very qualities of imagination, creativeness and drama which make its study especially worthwhile to those who will never have any further practical use for science in their daily lives.

The Fallacy of Miscellaneous Information

Here we find a belief in the usefulness of unrelated information such as the boiling point of water, the density of various substances, the atomic weight of different chemical elements, conversion factors from one system of units to another (how many centimetres are there in a rod or chain?), the distance in light years from the earth to various stars, the temperature of the sun and other astronomical bodies, the number of stamens or pistils in different types of plants, whether they have monocotyledonous or dicotyledonous seeds, the names of minerals, and the number of stages in scientific method. All too many science courses have attempted to make students memorize a series of dry facts which no practicing scientist knows. If he does happen to remember such a fact, the likelihood is that he will not trust his memory, but rather will go to one of the many technical handbooks available. While such miscellaneous information, especially if it is curious, exotic, or recherché, may provide an interesting moment in a dinner conversation, it is hardly of much use in the education of the intelligent citizen.

SPECIAL EDUCATION AND GENERAL EDUCATION

In recent years the term "general education" has come into use to designate that part of a student's education which is not meant to serve any special purpose in a professional sense. The "liberal education" of the recent past probably meant a "gentleman's education" and science was included in it because a gentleman was supposed to know a little about everything. "In its essence," wrote Professor Whitehead, "a liberal education is an education for thought and for aesthetic appreciation. It proceeds by imparting a knowledge of the masterpieces of thought, of imaginative literature, and of art. The action which it contemplates is command. It is an aristocratic education implying leisure."

Science was never a fundamental part of such education, but only a small part of what everyone should know. The major aim was "a large discoursive knowledge of the best literature", and the liberally educated man "will have acquired the chief languages, he will have considered the rise and fall of nations, the poetic expression of human feeling, and have read the great dramas and novels. He will also be grounded in the chief philosophies, and have attentively read those philosophic authors who are distinguished for lucidity and style". [19] Since this Platonic ideal of education did not give a primary place to science, the science courses grew up in terms of their own needs and appeals. While some attempt was made to show students "the wonders of nature", and "science (notably chemistry) in the service or man", it was simply assumed that any acquaintance with scientific subject matter, proofs and demonstrations would impart to the students the many virtues of "discipline" which would be "transferred", and the dubious aims listed in the "fallacies" of the preceding section. The result has been that the sole course in science taken in colleges by the liberal arts student is the very same introductory course in science taken by pre-professional students and future scientists or, what is often worse, a general survey of all the sciences.

Another characteristic that marked such courses on the college level was the fact that they tended to be given less and less by inspiring leaders in the field and were often assigned to junior faculty members, or to senior men who were no longer *au courant* with modern research. Gone forever seemed the days when introductory courses were taught by such commanding figures as Louis Agassiz or Benjamin Silliman. No matter what the curriculum was supposed to be, such inspiring men could not help but make the subject vibrantly alive to all the pupils; there can be no question but that such pupils—even if in later years they ceased to remember any of the facts and theories of science which they had been taught—would carry with them forever a healthy respect for the whole enterprise of science.

One of the effects of the rapid advance of science during the last 100 years has been that the elementary science course has had so much material to cover that the student has had no time to

appreciate the logic of the subject and is all too often reduced to memorizing figures, facts, proofs and formulas. Science courses came to resemble the survey course in history which began with the civilization of Ancient Egypt and ended yesterday. Courses in General Education are dedicated to principles which are more ambitious than the traditional courses of the past. The major virtue of the new General Education courses is that they are consciously dedicated to the needs of the non-specialist; in attempting to satisfy the requirements of the students it serves, General Education faces a situation quite unlike the programme for future scientists, engineers and doctors.

Since General Education in science is conceived primarily in terms of the need of the non-scientist, the aims of the courses and even the details of their design must reflect the reasons why we ask that all students study science. If we do not believe that students will learn *the* scientific method and then be able to apply it to every aspect of living, why do we demand some study of science from men and women whose primary interests lie in such fields as literature, fine arts, history, government, economics, philosophy, or sociology, and whose livelihood will be earned in pursuits that do not call for scientific knowledge? A number of somewhat related reasons come immediately to mind. Part of education consists in becoming acquainted with the great achievements of man, cultural and material. Science is plainly one of the major creations of the human spirit and ranks with philosophy, of which it was once a part, as a product of contemplating and investigating the "big questions" of human existence and the universe. As a subject that has occupied the best minds engaged in creative activity over the centuries, without science a study of civilization is incomplete. As we have seen, science has affected the material side of civilization as well as having been a creative force in its own right and in its influence at various times on literature, the fine arts, and even religious, political, and social thought. Hence, to be ignorant of science is to be ignorant.

Furthermore, our lives are affected today by science in more than a purely material sense. Science endows us with an understanding of the world around us that affords a delight to the mind, showing the interaction of the data of common experience, the enlarged vision obtained through the use of scientific instruments, the application of logic and the creative imagination. Science not only makes possible control of our environment, but enables us to predict, and thus be prepared for, events that we cannot control, such as storms and astronomical phenomena. A recognition of the cyclic repetition of natural events, and the causal explanation of them, removes the terrors that had previously accompanied the appearance of comets, eclipses, and even plagues. Only a few centuries ago, a comet was the occasion of apprehension, but today we may peacefully admire its appearance.

The popularity of books attacking science, or presenting seriously various kinds of pseudo-scientific nonsense, indicates that the reading public does not have the kind of sympathetic under-

standing that we set as one of the goals of General Education. Mr. Standen, to whose book I have earlier referred, generally attacks those aspects of science that are presented under the "fallacies" in the last section; but while most good scientists would agree that the subjects of his attack in many cases deserve the treatment he gave them, they would deplore the title and tone of the book and correctly resent the notion that what Mr. Standen is attacking in any way resembles science.

Finally, as pointed out in the opening section of this article, the non-scientist is being called upon more and more to make decisions in public affairs that affect the future of science. He has a double stake in the future of science: as one of the creations of the human mind of which he can be proud and as the source of innovations making possible a longer, healthier and more comfortable life. The latter demands an understanding of the steps by which science does produce results of practical importance. A test of understanding science might well be the question: Why are large telescopes and cyclotrons both important for the improvement of agriculture? To appreciate that the most abstract branches of science often provide revolutionary changes in technology, agriculture and medicine is not enough. A secure understanding must be present that the countries or societies which make the fullest use of the applications of science are those which have the most able corps of applied scientists, and the latter are available primarily where the general level of scientific research is high. Hence an intelligent guide to action, in those immediate realms where the fruits of science touch us the most, is possible only to those who have a deep appreciation of the whole character of the scientific enterprise and its relation to its social environment. At this point we get into a field where scientists do not agree among themselves—for instance, on the degree of "planning" possible in science —and there are no ready rules to be applied, just as there are no ready rules to be applied to the solution of problems in pure science. Yet there can be no question but what the citizen in a scientific age can profit by understanding as much as possible as a necessary condition for action in relation to the condition of science.

In his analysis of this question, President James B. Conant of Harvard University calls attention to the fact that in his experience, "a man who has been a successful investigator in any field of experimental science approaches a problem in pure or applied science, even in an area in which he is quite ignorant, with a special point of view. I designate this point of view 'understanding science". The particular form of General Education that he advocates is an intensive study of case histories of scientific investigation. There is no "hope by any short-cut methods to produce in a layman's mind the same instinctive reaction toward scientific problems that is the hall-mark of an investigator, but enough can be accomplished, I dare hope, to bridge the gap to some degree between those who understand science because science is their profession and those who have only studied the results of scien-

tific inquiry—in short, the laymen". [20] That more and more individuals have in recent years found themselves in positions of public life or business that have demanded some understanding of science on this level indicates that such education is an essential preparation for many aspects of life in the modern world.

Before going further, let us insist on one point. The new type of instruction is instruction in science, not merely a form of talking about science. The students learn definitions, follow proofs, analyse experiments and the construction of conceptual schemes and their eventual replacements; they solve numerical homework problems. They often do even more intensive work than before, but they do it in a different framework, since the new viewpoint insists that an enlargement of an understanding of science will not come from a greater dissemination of scientific information alone. The facts, set into a relevant social or historical setting, are used to serve such goals as: imparting to the student a "sympathetic understanding of science and the way scientific work is done" [21]; "education for citizenship in a scientific age"; study that looks forward to the student's "life as a responsible human being and as a citizen" [22]—in the sense of the preceding paragraphs, it must be kept in mind, not that of transfer. Hence, the whole outlook toward general education in the sciences may be summed up in the words "an intensive study of certain topics or certain phases of a problem . . . intended to introduce the student to that same sort of appreciation that comes to those who have studied some branch of knowledge with profit for many years". [23]

Two characteristics of such courses are immediately apparent to anyone who reads the literature on the subject.

1. A vast quantity of the material included in a traditional course has been simply jettisoned, in the conviction that the student in later years will forget most of the specific information imparted to him. It seems much better to delve deeply into a few topics than to skim lightly over a large number.
2. An effort is made to give every subject introduced in the course some relevance to the primary function of teaching science to the student: to give him a "feel for science" or an "understanding of science". The great stress on citizenship in a scientific age tends to make such courses include—in different degree, depending on the instructor—what may be called the social aspects of science.

The practical effects of science on our lives have aroused a passionate curiosity about the true social function of science. This is so not only among college students, but also among those who pursue adult education; we are told that "in the hands of a skilful tutor the exposition (to adults) of science in its social setting can lead to a more informed appreciation of the problem of citizenship". [24] This may be less marked among those adults who know some science and who seem to "prefer a presentation 'undiluted' by history and social effects; but those who know little science are more likely to be interested in a presentation based upon history and upon the effects of science on the individual

and society". [25] In considering the proved interest of the great number of college students and followers of adult education in the social aspects of science, we must exercise great caution lest we forget the intellectual part of science, the great adventure into the unknown, the use of the controlled scientific imagination, the application of logic to the facts presented by experiment and observation, the joy of discovery, and the genuine satisfaction of our curiosity about the way in which things in the world around us may be related to each other. We are told that "recognition of the fact that science is an activity distinguishable by its methods, rather than a simple pursuit of gadgets and tools, is still very rare among laymen. This situation is largely responsible for the continuance of the belief, still held by many, that science has no place in the liberal education of adults since it has no cultural contribution to make". [24] And in this connexion, we must always keep in mind that even in consideration of the narrow topic of the effects of science on society, we must not limit ourselves to the practical end-products which have improved navigation, manufacturing, the state of public health and the like, but must always keep in mind that new scientific ideas have themselves affected society in changing men's viewpoints toward himself and the universe, in a way which may be measured by the violent reactions of society or important groups in society to new ideas like evolution and relativity.

One of the primary goals of science teaching for non-scientists is to make the subject matter attractive to the student. Examples of free choice, as in adult education, indicate that most people prefer to make courses in literature—the "great books"—and, to a lesser extent, history. On this score, frankness demands our admission that science courses do not attract students. In adult education it seems to be the rule that only about five per cent of the course offerings are scientific; if the number is higher in our colleges and our secondary schools, the reason probably lies in the science requirement for graduation which forces students to make such course. The average non-scientist shies away from science courses because they are difficult and uninteresting. The physical sciences require mathematics and the power of abstraction, and the biological sciences require a strong stomach. Furthermore, there is always the handy rationalization that science and scientists are responsible for the ills that currently assail the world; in contrast to an earlier interest in science derived from the illusion that science would cure the ills of the world. There can be no question that the dry facts that must be memorized make an unpalatable dish for the average person; the frequently poor quality of science instruction in the secondary schools has been responsible for killing a more general interest in science and for creating a hostility toward any further study of science beyond that required for the obtaining of some academic degree.

A science course can be made interesting by a number of approaches to the subject, but one criterion to be constantly applied is relevance of the method of teaching and the contents of the

course to a general goal that the students believe to be important. The application of this criterion must first be made in considering the orientation of the course as a whole. Most people are interested in the creations of the human mind and we teach them to understand and to esteem such creations—in literature, music, the fine arts, philosophy, and so on. The facts of science are uninteresting by themselves, just as devoid of interest as the bare facts of literature or music. No one cares particularly about the date when Mozart was born, but the time in which Mozart lived takes on a measure of interest when we are told that George Washington must have danced to his minuets. The temperature at which water boils is of no interest, and even the variation of boiling temperature with pressure is of no great consequence unless related to a conceptual scheme that explains and correlates a wide variety of natural phenomena, i.e. the kinetic theory of gases.

Students studying physics usually find statics, or the study of vector forces, their resolution into components, their addition, and so on, one of the dullest and most difficult topics in the course. The average non-scientist takes no delight in computing the tension in a string supporting a weight when the weight is pulled to one side, nor in finding the turning moments of forces at the end of a ladder which in fact does not turn. On the other hand, experience shows that these same students will approach the subject of statics more willingly if they are brought to see the relevance of the subject, for example, if they have already studied the astronomy of the solar system and have become interested in understanding the forces that may hold that system together.

If science teaching is to be effective, it must display the creative imagination at work quite as vividly as does the best kind of teaching in literature and philosophy. The implication, it seems to me, is that the subject matter must be introduced—at least in part—in its historical context. At this point, however, I must warn the reader that I am writing in terms of my own teaching experience and that my view is conditioned by my profession of historian of science. Useful results are achieved with less emphasis on history than I give, although all agree that the intensive study of selected topics imparts a better understanding of science than an attempt to cover the whole range of physical or biological phenomena and that some episodes must be presented in full historical order and setting. The traditional course makes use of this historical approach in dealing only with the most recent science, e.g. relativity—perhaps because the teacher or the writer of the text-book actually lived through the stages of investigation and discovery in his student days and so still considers them in the category of "current events" rather than history. Since such an approach proves effective for the contemporary subject matter, why not use it for the earlier material as well. History has the virtue of showing the many diverse ways in which scientific discoveries have actually been made and no student can emerge from a dose of true history of science without appreciating that there is no simple method that has been consistently applied by the men

who have produced scientific advance. But it should be noted that the historical approach does not preclude logical analysis; any science course in which there was no attempt to show the numerous logical interconnexions between concepts, theories, and observed data would be, to my mind, a travesty.

Plainly, we are faced with a choice between presenting science as so many observed data, obtained by means of various experiments and observations, and leading to several general laws which are then applied to specific problems, or as a major human adventure into the unknown. The latter approach makes the subject matter humane by revealing the social and intellectual background of the research in question, the man behind the discovery, and the fumbling steps taken by even the greatest men of science when they leave the realm of the known.

It is a comon experience of all science teachers that the most recent discoveries in science offer the greatest fascination for the majority of students, in adult education as well as colleges. Unfortunately, the presentation of the exciting frontiers of scientific knowledge requires of the student a mastery of considerable previous information; it is not possible to build a physics course on radio-activity, relativity, quantum theory and nuclear physics. The question is, therefore, whether we can arouse from older or classical topics the same kind of exciting response as from the science of the present or very recent past. I believe that we can attain such goals to a limited degree, although it would be absurd to suppose that the theory of the inclined plane can ever again be made as exciting as relativity.

The frontiers of science excite the student because they take him to the edge of what is known and enable him to see the attack on the unknown as it is actually being waged, and also because the student feels that at last he is face to face with the science of his own time, the science that he reads about in the newspapers or hears about on the radio. It must not be forgotten that the student's excitement also mirrors the enthusiasm of the teacher who himself does not find the theory of the inclined plane as interesting as relativity! History cannot bridge the gap of centuries and make classical physics have the newspaper kind of excitement, but it can provide the excitement of the challenge of the unknown and the frontiers of knowledge. For instance, if Newton's law of universal gravitation is presented in the traditional way, and then applied to the solar system so that Kepler's laws may be derived from it, the student in general is not particularly impressed, especially if he has heard that "Einstein has proved Newton to be wrong anyway". On the other hand, if he has been studying the observed phenomena of the heavens and has seen how satisfactory the older geocentric system was, he is in a different position altogether. Copernicus's heliocentric system and the opposition it aroused then come as the beginning of a new approach to the subject of astronomy. Galileo's discoveries with his telescope, proving that the earth is in fact "only another planet", prepare him for the acceptance of the new system and the need for a new

dynamics that will embrace terrestrial and celestial phenomena under one set of principles. Kepler's three laws come as a surprise and raise the question of whether they imply the existence of a fundamental principle of which they are but the consequence, or whether like the "Titius-Bode law" they may be only a numerical relation without physical consequences. The Newtonian law of gravitation, linking together the fall of an apple and the "falling" of the moon, and implying Kepler's laws of planetary motion, may then come as a great climax, perhaps even rivalling the later student excitement about nuclear physics. In a word, whenever it is possible to trace the previous thought on any subject, then that subject can be presented as a great achievement of the creative spirit of man fathoming the unknown and will arouse in the student a considerable enthusiasm not possible by the customary logical presentation: after the fact.

One obvious advantage of introducing some history in a science course is that the student learns how many peoples or nations in different times have contributed to the great adventure. He sees the primitiae of science in the ancient Near East, the growth of abstractions in classical Greece, the magnificent state of science and research in Hellenistic times in and around Alexandria, the transfer of scientific activity to the Islamic world and the admixture of Hindu elements, and the eventual path to Europe and then to America and back again to the Near and Far East. The relation of science to society and to technology in these periods and places serves as an introduction to the study of current problems. Above all, the student sees the scientific enterprise over thousands of years as the result of the constant striving of the human mind to understand the world around us and not merely as the font of gadgets.

President Conant has made an eloquent plea for the analysis of case histories of scientific development as a means of enabling the student to learn the principles whereby scientific advances have been made, principles he denotes as the "tactics and strategy of science". In terms of particular examples or case histories, he would "show the difficulties which attend each new push forward in the advance of science, and the importance of new techniques; how they arise, are improved and often revolutionize a field of inquiry . . . illustrate the intricate interplay between experiment or observation, and the development of new concepts and new generalizations; in short, how new concepts evolve from experiments, how one conceptual scheme for a time is adequate and then is modified or displaced by another". In this view, it does not matter very much which particular scientific examples are employed, nor from which period in the history of science they are chosen. The choice of one example as opposed to another must be dictated by two possible considerations: the ease with which it is intelligible to the non-science student, and the particular developmental principles of science that it illustrates. Since no one would question that the paths to scientific discovery are the same now as they were in the preceding several centuries, an

example from the eighteenth century may serve to illustrate a particular point as well as, if not better than, one from the twentieth century; with the obvious advantage that the materials are easier to grasp because less previous factual knowledge is required "either as regards the science in question or other sciences, and relatively little mathematics". Then too, "in the early days one sees in clearest light the necessary fumblings of even intellectual giants when they are also pioneers; one comes to understand what science is by seeing how difficult it is in fact to carry out glib scientific precepts". [26]

It should be borne in mind that not all historians of science are agreed that the history of science provides the best method of teaching science to the non-scientist. Writing about the problem in relation to adult education, one of the leading historians of science has stated that in "attempting to give a groundwork in science to the non-scientist adult audience, the historical approach is often too bulky; we must teach this groundwork as a system of logical thought, not as a series of historical events". [27] There can be no argument on the word "bulky". Plainly, it is time-consuming to go into the stages whereby facts were learned and the theories proposed and tested, and the reasons why men were interested in those facts and proposed the kind of theories they did; much time can be saved by presenting directly the facts and the theories based upon them. But even if we suppose the "bulking factor" to be 50 per cent, I cannot personally see any great loss in being able to consider only half the scientific material in the traditional curriculum. The time should be long past when coverage was thought to be a useful goal in teaching science to the non-scientist. Since most of the facts and theories will be forgotten sooner than we like to believe, it should not make much difference whether our students forget a few facts or a great many. What is essential is that they retain an understanding of the nature of the scientific enterprise. Furthermore, it may be the case that memory will a little longer retain a few facts in broad contexts than a great many in narrow contexts. In any event, the socially and culturally useful goal of understanding science does not depend so much on the number of topics learned as on the significance given to them, which is, I believe, the most fundamental difference between the new General Education and the traditional courses, not only in the sciences, but in the humanities and the social sciences as well.

Granting that one of the aims of education which hopes to produce better citizens is to indicate the social implications of science, the very important question arises as to whether a course in "science and society" should be substituted for a science course. My own opinion is that instruction in the sociology of science cannot be a substitute for a science course, any more than a course in the history of science can. In General Education, the idea is to prepare students to comprehend some of the fundamental issues of science and society, not to preach methods of solving the problems. Fundamentally, the aim of such a course is to teach an

understanding of science in the many senses we have indicated above and to help prepare the student to cope in later life with the public problems of science. Needless to say, such students will learn a considerable amount of science as ordinarily taught—facts, theories, equations, methods, and the like—although in smaller number.

The reader should bear in mind that the degree of historical and sociological material introduced into science instruction will vary from one teacher to the next and that the introduction of such material does not by itself make a traditionally oriented course into a General Education course in the sense implied above. The differences lie in methods and points of view, and are partly implied in the supposed antinomy of "a system of logical thought" and "a series of historical events". For science is actually both of these, just as it is both a daring abstraction of the creative intellect and the source of gadgets. Traditional science education has insisted on the presentation of an enormous body of information and the hope (usually not justified) that the student will learn, *en passant*, the scientific method or critical thinking. General Education insists that whatever topics are introduced must be made interesting and relevant to the student in terms of his natural interests, his experience and his other studies, and that the material taught will not help him to understand the methods of science, the nature and growth of the scientific enterprise and its place in society, or the character of scientific knowledge, unless the teacher makes a conscious effort to relate the subject matter at every stage of the course to the goal of "understanding science" and the preparation for citizenship in a scientific age.

Above all, almost every subject that the student learns in such a course will be better understood by him than if he had learned that subject in a traditional course. For he will have learned not only the experimental or observed data, the theory built upon it, and the applications of that theory to some specific problems, but also how that theory is related to others (both in logical connexion and that of time and space), how it came about, how it was eventually modified or replaced, what its philosophical implications have been and what philosophical currents influenced its formation. In other words, the student will not learn his science in the customary text-book abstraction but rather as a part of the continuous creation of the human mind. And, above all, he will know that whatever he has learned is not a final truth but only one stage toward a more comprehensive knowledge.

IMPLICATIONS OF COLLEGE GENERAL EDUCATION PROGRAMMES FOR PUBLIC EDUCATION AT LARGE IN THE SCIENCES

Having examined the development of scientific education and some of the failings of current education and aims of General Education, we must now consider how much of the principles underlying the latter are applicable to public education at large.

My thesis is that the goals set for the General Education in science of the non-science college student are vitally important for the non-scientist citizen in the modern world and that their widespread application on all levels represents a desirable goal for society.

Up till now, adult education has been conspicuous for the relatively small amount of science taught. Science courses account for not more than five per cent of the total in such education, taking an average for Europe and America. The reason for the unpopularity of science probably lies in the previous science courses, whether taken in secondary school, college, *lycée,* or *Gymnasium,* and also in the type of course offered in the adult education programme. An English report noted that "for the majority of adults interested in adult education it is the approach by way of the social significance of science that is most successful in arousing interest, and in evoking the effort necessary for regular and effective attendance during a course of 12 or more lectures. While the social approach to science is far from being the only important one for the ordinary citizen, it is manifestly the approach of the moment. Scientific workers are accustomed to being opportunists in their own fields, doing what they can, when they can, and how they can. They would do well to employ similar tactics in bringing their subject to the notice of others". [28] I believe that the General Education approach may help to make our adult education in science more attractive in much the same way that it has for the college student. Increased enrolment, and the willingness of students to attend an evening course regularly for a period of two years, characterized the introduction of a General Education course in the physical sciences in the Massachusetts University Extension programme.

But even if the aims and methods of General Education in the sciences seem to be as well adapted to adult education as to college education, we cannot assume that the same holds true on the secondary school level. Here I must confess that I speak as an amateur; my only contact with secondary school education has been through a sampling of the publications available on the subject, talks to teachers who are interested in improving the quality of their own courses, and the courses I myself took when I was in secondary school—which were deplorable examples of the cut-and-dried or take-it-or-leave-it sort of thing. It seems plain that the distinction between science and non-science student is not at all clear at the secondary school level and that one cannot therefore divide the students into the two categories that are so convenient at the college and the adult-education level. These very courses may be influential in stimulating students to become scientists or in turning them in other directions of study. Even the amount of information to be included differs from the college or adult-education courses.

There seems to be general agreement that certain facts about medicine and public health are of use to all students: knowledge about cleanliness, diet, posture, exercise, and rest. In American

schools there is not only the division between students who in college will study science for professional reasons and those who will not, but also between the future college students and those whose education will stop after secondary school. Some of the latter will need specific instruction in mathematics, physics, chemistry or biology in order to become mechanics, accountants, bookkeepers, farmers, technicians of various sorts and so on, while others will not.

Despite their heterogeneity with regard to the future, these students have one feature in common: they will all become citizens in a scientific age. If the goals of General Education are socially valuable, they must find some place in the secondary school curriculum. Severe limitations are imposed by the relative immaturity and lack of experience of the students; in this aspect the problem is in many ways more difficult than that faced in adult education or in college. An even more serious problem in improving the secondary school education in science arises from the generally poor preparation of the teachers, many of whom never intended to become teachers of science.

Such men and women may have taken only one survey course in science in college or in normal school and would never have taught science had not the principal of their school given them the assignment. Even those who have followed special programmes preparatory to becoming science teachers may on the college level have had no more than an introductory course in physics, chemistry and biology. This means that they have never gone far enough in any field of science to reach the frontiers of knowledge and to learn what research consists in. In other words, they have never advanced to the point at which science really becomes interesting and they all too often become drill-masters swaying on the edge of ignorance. Furthermore, they have no acquaintance with the history, philosophy or sociology of science.

If this were not bad enough, we must face the fact that many teachers of science in secondary schools do not "understand science" in the sense in which this expression has been used in the preceding pages. The American literature on the goals of scientific education is often appalling to the scientist. The five fallacies discussed above are all present, and science is supposed to help the students to make better social adjustments, to make democracy more secure, and to solve the problems of daily living from the repair of homes all the way down to the purchase and preparation of food. Even in the elementary school (where the "basic purpose" is "the development of desirable social behaviour"), science, with its dynamic aspects, its insistence upon critical-mindedness and better understanding of the world, and its demand for intelligent planning, has, we are told, "a large contribution to make to the content and method of elementary education". [29]

However, there is a prospect of amelioration in the secondary school situation. Secondary schools are very sensitive to educational trends in colleges. Teachers in the secondary schools in

America continue to take courses and in many cases obtain salary increments for doing so. A concerted effort by teachers in colleges, teacher-training schools and graduate schools of education may re-educate some of these teachers so that they can do a better job in the sense indicated above. Interest in improving secondary school education is widespread and growing and many of our leading scientists are dedicating themselves to this problem.

Any consideration of the education of the public with regard to science must take account of the fact that the education provided by colleges, technical institutes, secondary schools and adult education centres is supplemented on a mass scale by our radio, cinema, television, magazines, newspapers, and science museums. In America, even "comic books" must be included; two of the latter, which I have seen, [30] are devoted to the subject of nuclear physics and atomic energy, and I must confess that I cannot envisage their having a genuine educative function on any level. These mass media seem to be devoted chiefly to the dissemination of information about the latest scientific research, or at times the scientific explanation of various experiences of the household or daily life. It is certainly extremely useful to keep the progress of science before the public eye, and when done at its best, scientific reporting performs an extremely useful function in our society. On the other hand, I believe we must face the fact that the dissemination of information, however interesting and useful it may be, does not provide a better understanding of science. Indeed, it may only serve to re-enforce fallacious notions held by many people—and the wide-spread use of the word "miracle" in describing the latest advances in science, especially in medicine, seems to indicate that the nature of scientific discovery is still shrouded in mystery.

There can be no doubt that the radio, television, newspaper, and magazine do much to stimulate an interest in science. So do the science museums, as their large attendance records (especially at planetaria) well demonstrate. In this way, much of the deadening effect of the secondary school science instruction has been ameliorated and large sections of the population have been prepared for a more serious education in science. The latter has been partially provided by lectures series (which, however, are local) and by books. I believe that it is still mainly through books that attempts have been made to impart widely the kind of scientific education that seems to be needed for the age in which we live.

The Florence conference of Unesco gave serious consideration to "Various methods for the popularization of science", especially to "bring home to the masses the importance of the protection and appropriate use of natural resources and of the influence of science on the well-being of society". Here is only a beginning of a concerted attack on a problem of vast implications. The protection and use of natural resources is of obvious importance, but far greater in the long run may be a better appreciation

of the nature of science itself. That science can make the decisive contribution to the improvement of the physical existence of man is without question, but in order to do so most effectively it must receive the sympathetic support of an intelligent public who must learn the difficult lesson that the most practical benefits of science are often the issue of the most abstract and seemingly useless kind of research. Furthermore, it must be recognized that science does not by itself produce changes in the world; that making available the fruits of science to the greatest number of people is a problem for all the members of society to face. If the goal of understanding science—in the sense of General Education described earlier in this article—and of appreciating its social character and effects is worth while to society, then we must look forward to the day when science writers (of the press, radio and television) will address themselves to it. Aid must be enlisted from advisory groups of scientists and educators and many of the science writers will need to become better informed than they are at present. Which of these mass media are best suited for increasing the understanding of science of the general public, and how this may best be accomplished, are questions that merit the most serious kind of study.

It may well be the case that the world needs more progress in the relations between individuals, groups, and nations than it does in the physical condition of man; who dares to say that the world needs scientific progress more than ethical progress? But the physical condition of man can be improved only if the fruits of science are produced; hence, every individual has a stake in scientific progress. We return full cycle to the thesis that the greatest need in scientific education is a programme of teaching what science is and what science does and how it affects the lives of each of us, what science can do and what it cannot—in other words "understanding science".

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GUIDE TO FURTHER READING

The following list contains some books and articles supplementing those in the references above, which the writer has found valuable in assembling the material and which may be of interest to the reader. This list is highly personal and selective. Almost all the references are of American origin, as the aim of the article has been to present some of the possible implications of American experimentation in General Education. Additional literature on this subject may be found in Earl J. McGrath, "A Bibliography in General Education", *Educational Record 21:* 96-118, 1940; William Nelson Lyons, "A Further Bibliography on General Education", *Journal of General Education 4:* 72-80, 1949 [a reprint of the above two bibliographies is available from *The Junior College Journal*, N.W. Washington, D.C.]; Vaden W. Miles, "Bibliography with Annotations for Science in General Education at the College Level", *Science Education 35:* 159-76, 1951 [the author, a member of Physics Department, Wayne University, Detroit, Michigan, has also prepared a mimeographed "Bibliography with Annotations for Science in General Education, 1951"].

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THE BULLETIN OF THE ATOMIC SCIENTISTS

"A Magazine for Science and Public Affairs"

by

EUGENE RABINOWITCH

The author, a chemist, physicist and biologist, is a Research Professor at the University of Illinois. His Photosynthesis *is a standard book in the field. He is the editor and co-founder of the* Bulletin of the Atomic Scientists. *During the war he was connected with the American atomic energy project.*

In the summer of 1945, the success of the wartime atomic bomb project in the United States had become a certainty. But people at large had no inkling of what was in store. Many of the scientists, who knew, felt restless and frustrated. For four years they had worked hard to convert the fantastic dream of a nuclear explosion into reality. They were spurred by the fear that the Germans might solve the problem first, assuring Hitler of victory. Now, the Hitler empire had crumbled. The world was safe from a German atomic bomb, but America was about to acquire one. The political and military leaders who knew that the bomb was coming saw in it a welcome addition to their arsenal and were impatient to try it out on the remaining enemy—Japan. The eagerness with which they sought, at the same time, the assistance of the Soviet army in Manchuria, shows how little they were aware of the overwhelming power that was soon to be theirs.

For scientists, on the other hand, the coming of the bomb signified a new era in world history. The tragic aspects of this era —which have since unfolded themselves to the world—even then were clear to them: the inevitable acquisition of atomic weapons by other industrialized nations—first of all, by the Soviet Union; the consequent capacity of nations possessing bombs to threaten every other nation with sudden destruction; the end of national security in the accustomed sense of the word; the frenzied race of atomic armaments; the growing mistrust and isolation of nations from each other, transforming them, as it were, into besieged fortresses; the curtailment of freedoms in democratic countries, forced, in part, by legitimate security considerations, but largely by fear and confusion; and last—but not least for the scientists—permanent subordination of scientific research to military aims. All these future calamities haunted atomic scientists in their sleepless nights, and were discussed by them in hushed conversations in the corridors of the Manhattan Project laboratories.

The only chance scientists saw of preventing these ominous developments and the catastrophe of atomic war that loomed at

their end, was to make the world realize that the emergence of atomic weapons called for an entirely new beginning in the relations between nations. As a first attempt to impress upon the national leaders that the release of atomic energy necessitated such a change in political and military thinking, a group of scientists petitioned the President to forego the use of the atomic bomb in Japan. In a memorandum to the Secretary of the Army, another semi-official group of Chicago scientists pleaded that the military advantages, which the use of the bomb in Japan might bring, be weighed carefully against the damage this use might do to what (they said) should be the paramount long-range objective of American policy—the prevention of a future atomic war. Neither the petition nor the memorandum were answered. The leaders of America were too overwhelmingly concerned with bringing the war to a rapid end, too unfamiliar with the fundamental laws of physics, to be disturbed by the fact that the mastery of man over the powers hidden in the atomic nucleus was about to be revealed to the world in the destruction of a city, and the flaming death of 100,000 men, women, and children in the flash of a single bomb.

The leaders of the world were not prepared to start it on a new path just because a nuclear chain reaction had been proved possible. A great educational campaign was needed to make them comprehend it; or to make the peoples themselves rise and tell their leaders that they wanted a new world community.

The recognition that a job of "atomic education" was needed, and that only scientists could do it, led to almost simultaneous formation of the atomic scientists' associations in Chicago, Oak Ridge, New York, and Los Alamos, which soon coalesced into the Federation of American Scientists; the British Atomic Scientists' Association was founded a little later with the same purpose.

The *Bulletin of the Atomic Scientists* was launched in December 1945, by the Atomic Scientists of Chicago, as an organ of this crusade. It set itself three aims. The first was to support scientists in their educational campaign, by objective and documented information about relevant political developments, and to open to them a forum where they could discuss how scientific attitudes and methods could be best brought to bear on political developments.

In the second place, the *Bulletin* addressed itself to the men in power, or wielding political influence, bringing to those who wanted to listen—and for a time, scientists were listened to—an understanding of the implications of modern science for war and peace.

In the third place, the *Bulletin* directed its appeal to articulate laymen—the newspaper and radio commentators, the leaders of civic groups, the high-school and college teachers—all who could help in explaining to the masses the changes that science has wrought in their lives.

There never was much illusion about the chances of success in this campaign. Men versed in history, and in politics as the art

of the possible, patronizingly explained to scientists that the world cannot be reformed in a few years, and that it was impossible to bring the Soviet leaders over to co-operation with Western nations in atomic matters. These advisers did not understand that the scientists knew of these difficulties only too well; but that for them, the word "impossible" meant "highly improbable", and that they saw it their duty to *try* anyhow—as a doctor fights for the life of a patient even when he realizes that the odds against him are overwhelming. However narrow the hope, an attempt to prevent an international race of atomic armaments had to be made. After all, it was argued, the self-interest of all nations, including the Soviet Union, lay in preventing this race; and if only agreement on the measures objectively necessary to achieve this aim could be reached, a door would be opened to sensible co-operation in this—and later perhaps, also in other, wider fields of mutual security and economic reconstruction.

The first two years after Hiroshima had been, for the scientists and for the *Bulletin,* a period of enthusiasm and of success beyond initial expectations. The fight for civilian control of atomic energy in America, started by scientists in anticipation of inevitable defeat (was not General Groves, in the eyes of the American people and Congress, *the* true creator of the atomic bomb!), had found unexpected resonance in the still traditionally anti-militaristic American public opinion. With the scientists providing the spearhead, and the *Bulletin* beating the drum, the May-Johnson Bill was defeated, and the McMahon Bill, creating a civilian Atomic Energy Commission, passed, despite the unofficial—but for that not less stubborn and resourceful—opposition of influential sections of the military.

The international control of atomic energy, which had been urged in the very first memoranda and public statements of atomic scientists, and whose mechanisms were first analysed in numerous *Bulletin* articles, rapidly became the official programme of the American Government (even though a few months earlier, this same Government seemed to be committed to keeping atomic energy a "sacred trust" in American hands). An inspiring plan was outlined by a State Department panel, including Dr. Robert Oppenheimer, the wartime head of the Los Alamos laboratory, and Mr. David Lilienthal, the head of the Tennessee Valley Authority, who had been introduced to atomic energy problems by scientists at a meeting called in September 1945, at the University of Chicago. With an unexpected lack of opposition, this bold plan was accepted by the State Department. With equally unexpected readiness, the Soviet Union agreed to the principle of international control. In the United Nations Atomic Energy Commission, first assembled in June 1946, the "Acheson-Lilienthal plan" was introduced by Mr. Baruch. The Soviet representatives stalled, but gradually conceded many of the measures needed to make the control effective. They remained unalterably opposed to one

important point of the plan—the international management of atomic energy plants and international ownership of atomic stockpiles. They also rejected the abolition of the veto in the Security Council in voting on sanctions against violators of the control covenant—a provision tagged to the "Lilienthal plan" by Baruch.

For three years, the *Bulletin's* main preoccupation was extensive reporting and interpretation of the atomic control negotiations. It discussed compromise plans, and suggested entirely new approaches—such as an international moratorium on atomic industry. The *Bulletin* sought to enlighten public opinion on the relation of atomic energy to atomic weapons, and on the essential technological aspects of atomic energy controls; while the press and political speakers emphasized the less essential, but more familiar aspects—the application of the veto to atomic sanctions, or the "dismantling" of American atomic bombs. On two occasions —in 1948 and again in 1950—the *Bulletin* published summaries of the atomic control negotiations. The second one, "Minutes to Midnight", containing all the main documents, and a running history of atomic control negotiations, as well as a review of alternative proposals and an estimate of the possibilities of compromise, has found considerable use as a text-book in American colleges and adult education programmes.

While keeping up its campaign stressing the need for international control of atomic energy and for the minimum conditions required for its success, the *Bulletin* was not unaware of the fact that as negotiations dragged on, and the tension between the Soviet Union and the West increased, the probability of a successful conclusion of a control convention, never high, had decreased to almost zero.

When the hope faded that the danger of destruction in a future atomic war might sober all the political leaders of the world—from the most hidebound conservatives to the most aggressive revolutionaries—a crisis arose in the activities of the scientists' organizations. The expectation of success, however flickering, was enough to sustain for two years an enthusiastic effort by hundreds of scientists who never before had had any inclination to dabble in politics. The disillusionment was deep. Many organizations closed down. Among them was the Emergency Committee of Atomic Scientists, headed by Einstein, which had provided financial support for the educational activities of scientists, and also helped to balance the budget of the *Bulletin.* (At the high point of the educational campaign, the *Bulletin* had a press run of 20,000 copies, of which a large part was distributed in bulk to different organizations, or mailed free to all who—it was felt—could use it, including every member of Congress.)

The question whether the *Bulletin,* too, should wind up its activities, lay heavily on the minds of its publishers. The magazine could not be expected to become a profitable undertaking. Some of the most prominent friends of the *Bulletin* advised it to quit—to decide that the world had been amply forewarned, and that if

mankind insisted on going down to its doom, there was nothing scientists could do about it. "Let's go back to our laboratories and calculating machines and explore the secrets of nature—as long as we are permitted to do so! After all, this is what we really like —and what we are paid for."

Against this advice of disillusioned colleagues, there was a strong feeling (shared by the majority of the *Bulletin's* sponsors and by a faithful readership), that the *Bulletin's* continued existence answered a definite need. For better or for worse, science and statecraft, science and political economy, have become entangled. The atomic bomb has been only the most spectacular example of this entanglement. Even if no solution of the atomic bomb crisis was in sight, numerous other problems, caused by the impact of scientific and technological progress on political decisions (and vice-versa) were bound to arise from day to day.

At home, the Government monopoly of atomic energy, the rapid growth of an industry that appeared a socialist island in a capitalist sea, presented many aspects that required thoughtful analysis. The impact of secrecy restrictions on the progress of science and technology offered a continuous challenge. The harassing of scientists by loyalty checks and investigations, foreseen in 1945, was not slow to materialize, particularly after the revelation of the treacherous activities of Fuchs. It widened into a general attack on the academic profession, and into attempts to enforce ideological conformism. To counter this trend by intelligent opposition, to explain the limited importance of security and its dangerous effects on the rate of scientific and technical progress, became a continuous preoccupation of the *Bulletin.* The need to obtain large-scale Government support of science in America without undue interference with the freedom of research, through agencies such as the National Science Foundation, had to be explained to the public and to Congress, that did not (and still does not) understand that unfettered fundamental research is the basis of all technological advance.

The potentialities of various atomic weapons—the hydrogen bomb, radioactive dust, "tactical" fission bomb—had to be discussed rationally, however difficult the increasingly impenetrable veil of official secrecy made such discussion. The *Bulletin* has become a recognized source of reliable information in this field, in which the general press featured, with equal prominence, reliable reports on new atomic bombs in the United States and abroad, and tales about cosmic-ray weapons, interplanetary platforms, shooting cyclotrons, and atomic hand grenades.

Civil defence was another problem to be faced realistically. In September 1950, the *Bulletin* published a special issue dealing with its passive aspects; a year later, a second special issue emphasized industrial dispersal as an "active" form of civil defence, that would not only decrease the damage caused by an atomic attack, but also reduce the probability of such an attack by depriving the aggressor of worthwhile targets. At one of the early meetings of atomic scientists in 1945, the three answers to the

threat of atomic warfare were said to be: world government; if no world government, international control of atomic energy; if no international control, dispersal of industries. With the first—and only adequate—solution not even attempted, and the second one stalled, the third one has become more important than ever—and yet, the understanding of its importance has made little progress since 1945.

In the international field, a question of special concern for the *Bulletin* was and remains the free movement of scientists and free exchange of scientific information. Recently, travel restrictions which have made it virtually impossible to hold an international meeting of scientists on American soil, have shown that this problem becomes more and more acute as the arms race gathers speed. It is a hard uphill fight to convince public opinion that intellectual progress everywhere, including America, depends on the continuation of the traditional free exchange between nations of men and ideas. For a public that confuses science with technology, it is difficult to conceive that America's own interest calls for assistance in the development of science everywhere in the world; that if some countries choose to withdraw their scientists from the world community, it would be to our disadvantage to retaliate with similar measures. The fight for openness in science remains a lasting task of the *Bulletin*.

While science applied to war technology threatens the world with destruction, science applied to increasing food production and industrial output, combating disease, and controlling population, offers to modern statecraft a challenge the like of which has never existed before. For the first time in history, it has become possible to take an inventory of the human and material resources of the world, and to analyse the ways in which these resources could be used to create improved conditions for all nations. But, it has also become clear how enormous are the difficulties which beset this project, and how superficial was the optimism in which scientists were inclined to indulge—a *naïveté* which still survives in many quarters. It is only in the last few years that the West has become aware of the grave problems relating to the rehabilitation of the prolific nations of Asia and of its own stake in their solution. As in the case of atomic energy, the probability is high that the development in this field will remain determined—as it has been in past history of mankind—by blind national passions and irrational movements of desperate masses. Again, a challenge is presented to American and European statesmanship—to substitute for these blind forces the powers of reason, directed by scientific analysis and supported by the creative and productive potential of the world.

For the last two years, the *Bulletin* has devoted an increasing amount of space to population trends, energy resources of the world, agricultural productivity, and the importance of agrarian reform. Even many of the scientists among our readers had been

unfamiliar with this field before. It is an important function of the *Bulletin* to awaken their interest.

Because of this broadening of the subject matter, the subtitle "Magazine for Science and Public Affairs" now more adequately describes the purpose and content of the *Bulletin,* than does its main title.

In dealing with such topics as the civilian control of atomic energy at home, or its international control by the United Nations, the editors of the *Bulletin* felt that they represented the almost unanimous opinion of the scientific community in America and abroad. They could, therefore, express themselves strongly and positively. After the United States Atomic Energy Commission had been established, and the international control talks in the United Nations had come to a standstill, many of the subjects treated by the *Bulletin* became controversial, with opinions divided among the scientists themselves. Under these conditions, to maintain scientific detachment and avoid a partisan approach, the *Bulletin* adopted the policy of giving space to different points of view, particularly if they were shared by prominent scientists in America or abroad, however much they might differ from each other and from the opinions of the editors. In assessing Blackett's book *Fear, War, and the Bomb,* the *Bulletin* printed no less than four reviews, ranging from endorsement to sharp criticism of Blackett's theses. In discussing the duty of scientists in the present political situation, opinions ranging from the support of the Stockholm Appeal, and the refusal to work on military objectives, to the advocacy of complete mobilization of scientific manpower, have been given expression in the *Bulletin.* The *Bulletin's* conviction is that its readers—and its scientific readers, in particular—are able to form their own opinions and do not need to be "protected" from the points of view which are presently unpopular, or with which the editors disagree.

The editors have not felt obliged to conceal their own opinions; but they have attempted to avoid categorical judgment where wide disagreements were apparent between large groups of scientists. On other issues they felt they could be more outspoken. Attempts to impose dogmas on science, especially those originating with political authority, have been unequivocably condemned. This is a matter on which scientists who are at all free to express their opinions are more nearly unanimous than they ever were on such subjects as the control of atomic energy. Nevertheless, the pages of the *Bulletin* remain open to any scientist, in America or abroad, who wishes to present factual or logical arguments in favour of the suppression of "Mendelian" genetics, or in support of the "new biology" which the Soviet Union is trying to substitute for the science evolved by an international enterprise in which Russian scientists had taken a conspicuous part.

Another editorial conviction, from which the *Bulletin* has never swerved, is opposition to the idea of "preventive" war and, more

generally, to the idea of war as a means of achieving political aims. An objective discussion of the potentialities of atomic or radiological weapons, or even an analysis of the possibility of wiping out all life on large areas of the globe, involves no surrender for the *Bulletin* to the idea of the inevitability (not to speak of the desirability) of a new war; any more than the discussion of epidemics in a medical journal means toying with the plan of using bacteria or viruses to achieve political purposes. When Air Force generals, in 1948, described how Soviet cities could be annihilated by strategic bombing, or when a popular American magazine, in 1951, devoted an infamous issue to the imaginary course of a third World War, the *Bulletin* remained true to its original conviction: that scientific weapons have made war as "continuation of policy by other means"—to use Clausewitz's famous definition —obsolete.

A few words about the organization of the *Bulletin.*

From 1945 to 1949, it was published by the Atomic Scientists of Chicago. With the decrease in activity of the scientists' organizations, it was not considered expedient for the *Bulletin* to remain the property of one of them, and the publication was transferred to a specially constituted Educational Foundation for Nuclear Science. The latter consists of 26 of the most prominent scientists of America, with Dr. J. Robert Oppenheimer as chairman and Dr. Harold C. Urey as vice-chairman. Among the members are E. U. Condon, Leo Szilard, A. H. Compton, Albert Einstein, Linus Pauling, Edward Teller, to name only a few.

After the tragic death, in 1949, of one of the founders of the *Bulletin,* H. H. Goldsmith, the author of this article has continued as the *Bulletin's* editor. His colleagues on the Editorial Board are a physicist, Dr. John A. Simpson; a chemist, Dr. T. Harrison Davies; and a social scientist, Dr. Edward A. Shils; all three, professors at the University of Chicago. In the summer of 1951, a professional journalist, Mr. Michael Amrine, joined the *Bulletin* as managing editor.

In common with other American journals of restricted circulation, the *Bulletin's* income from subscriptions and advertising does not cover the costs of its publication, although the editors contribute their time free, and the authors receive no honorarium. Since the demise of Einstein's committee, the deficit has been covered by donations from individuals, and grants from foundations. In soliciting support, the *Bulletin* has made it very clear to individuals or organizations providing it that it intends to preserve complete independence in its editorial policy.

With free circulation now drastically curtailed, the press-run of the *Bulletin* has been reduced to 7,000-8,000. A recent grant has been used, in part, to increase the *Bulletin's* distribution abroad, particularly to libraries.

The influence of the *Bulletin* is, however, much wider than its circulation. It has been called the "most widely quoted journal in America". Many news commentators and editorial writers have become accustomed to basing their judgment on atomic energy

developments and political problems affected by science, on the information and commentary they find in the *Bulletin.* A well-known radio commentator writing to us in 1949 called the *Bulletin* "one of the most valuable publications which comes across my desk". More recently, Roland Sawyer, writing in the *Christian Science Monitor* on 6 December 1951, said:

"This correspondent has saved nearly every issue of the *Bulletin of the Atomic Scientists* since its inception in 1945. . . . The nuclear scientists are constantly striving to make their influence felt upon the course of political events at a high level at home (as they did in the passage of the United States Atomic Energy Act of 1946), and to speak to their counterparts, as well as to all men, abroad. The *Bulletin of the Atomic Scientists* is one, probably the most consistent available medium, for so doing."

Many scientists in Europe also have praised the objectivity of the *Bulletin,* both in reporting new developments and in presenting comments on them by people from different lands and with different political allegiance. Bertrand Russell has expressed his opinion of the *Bulletin* in these words:

"I have read it carefully from its first number onward, and I have found in its pages what is very difficult to find elsewhere, namely, a well-informed and impartial assessment of facts and policies free from the distorting bias of party or nationalist prejudice. I think it very desirable that it should be widely read not only in America but throughout the civilized world."

Another eminent European, Dr. Hans Thirring, Director of the Institute for Theoretical Physics at the University of Vienna, wrote:

"Among the journals written in non-technical language for a broader public, it is much more serious than nearly all the weeklies and monthlies which reach us here from beyond the Atlantic, and within its group it appears to be almost the only one worth being read."

A BASIS FOR SOCIAL PHYSICS

by

JOHN Q. STEWART

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The impact of physics on society is threefold. There are the social effects of technology and mechanical invention. There is awareness that modifications in popular philosophy are brought about by what science teaches concerning the nature of the universe. But still unknown to most people is the nucleus of researches which are strengthening studies in the social sciences by bringing to them new insight and organization in accordance with methods and principles which have succeeded so wonderfully in the triumphant mathematical sciences. Merely verbal logic which traces back to Aristotle still comprises the sole intellectual equipment of too many practitioners of social disciplines, although physical science freed itself from those same archaic bonds as early as the seventeenth century.

In its broadest sense social physics can be interpreted as including all studies of a mathematical type relating to human behaviour. An alert critic, Professor Otis Dudley Duncan, Chicago University sociologist, writes: "In content such studies range from experimental psychology to world demography, and in method from the inductive use of statistics demonstrating empirical relationships to the development of formal mathematical models applied to deduction of behaviour. It is a good question as to whether so many diverse types of enterprise can be profitably embraced within a single discipline."

In Princeton University, with support from the Rockefeller Foundation, we have a small project devoted to the development of social physics. Our opinion is that it is still too early to answer Duncan's question with either a Yes or a No. Our immediate quest is for uniformities in social behaviour which can be expressed in mathematical forms more or less corresponding to the known patterns of physical science. Social physics so defined analyses demographic, economic, political, and sociological situations in terms of the purely physical factors time, distance, mass of material, and numbers of people, with recourse also to social factors which can be shown to operate in a similar way to two other physical agents, namely, temperature and electrical charge.

The idea of a physics of society, today rapidly gaining adherents, is not nearly so novel as it may seem. The first to use the term social physics was Auguste Comte about 1820, followed independently in 1835 by Quetelet, the Belgian astronomer and all-round scholar. Comte used it as synonymous with his new science of sociology, to which however he gave nó physical or mathematical structure. Quetelet was deeply impressed by what now one takes for granted—the regularity of many types of numerical social data. He popularized the statistical concept of the average man, while warning against its misuse. The term social physics in his limited sense was employed for many decades in England and elsewhere to denote the collection of demographic, sociological, economic, and medical statistics, and their interpretation in accordance with the mathematical principles introduced by Laplace and Gauss.

Important beginnings along the same lines had been made long before by two Englishmen who were early members of the Royal Society, John Graunt and Edmund Halley. The latter's name is perpetuated in the great periodic comet; but he was much more than an astronomer, as Graunt was more than a merchant. In 1693 Halley published the first mortality tables, which he based on data compiled for deaths in the city of Breslau, and described the fundamental theory of annuities and life insurance.

In those free and vigorous days it was not considered odd for a leading astronomer to make a significant contribution to demography, but as specialization of scholarship and research set in, sociology no longer kept its early rapport with physical science. Many of the contributions to social physics in the nineteenth century were made by writers in the social field whose knowledge of physics was limited; they are often buried in the prolix writings which became the fashion among social scientists—a far remove from the succinct statements in 1662 of Graunt's *Natural and Political Observations*. A few leading examples may be listed here.

Henry C. Carey, self-taught Philadelphia publisher who became the pioneer American sociologist and economist, was in the 1850's quite aware of numbers of people and distance as social factors, and of their neglected importance for the colonial policies of Britain. He saw deficiencies in the contemporary classical English school of political economy, which had set up what Dr. Walter Isard, of Harvard, has called in another connexion "a wonderland of no dimensions".

In 1872 a popular periodical, *Scribner's Monthly*, carried an important article which the literary-minded editors of similar publications today would have rejected without reading, entitled "The Advance of Population in the United States". In it a Bavarian-born civil engineer and geodesist, who had a successful career in the U.S. Coast and Geodetic Survey, J. E. Hilgard, defined the gravity centre of population for the United States and described its steady motion westward along or near the 39th parallel of latitude. This is the centre of which so much—critics say too much—has been made by the Bureau of the Census ever since. A fore-

cast which Hilgard hazarded of its future motion has worked out fairly accurately so far.

However, while the centre of gravity of the swarm of residents of the United States has been moving westward through all the 17 censuses from 1790 to 1950, the swarm itself has continually expanded in size in such a way as to keep the greatest densities of population still in the Virginia-to-Massachusetts belt centred on New York City, where they were at the beginning.

Lester F. Ward was another self-taught American investigator; he was a leading paleobotanist before he gained recognition as a sociologist. Probably he would have been surprised at the interpretations his followers have given to some of his ideas. He anticipated in principle our own theory, described below, of "dimensions of society" when he wrote: "The three ultimate elements in mechanical theory are mass, space, and time. Motion being assumed, the rate, or velocity, is equal to the space divided by the time. . . . The theory of units is applicable to every true science in proportion as it can be reduced to exact measurement. In mechanics, astronomy, and physics the phenomena can, for the most part, be thus reduced; but in the more complex sciences, at least in their present state, this can be done only to a limited extent. It must not, however, be inferred from this that exact laws do not prevail in these domains. They are as rigid here as in the simpler ones, and the only imperfection is in our knowledge of them. The acceptance of this statement is what constitutes scientific faith. Those who do not accept it, and doubt the uniformity and invariability of natural law in the fields of life, mind, and human action, simply lack faith in the order of the universe."

A contemporary of Ward's, Simon Newcomb, who likewise spent many years in the employ of the Government in Washington and was the leading mathematical astronomer of his generation, ventured to pen a text of economics; but it was a cold and formal presentation and he was disappointed at its reception. The quantity theory of money, and fluctuations in the cost of living, were emphasized, to the advantage of later investigators. Notwithstanding its dullness, this book is more alive than the earlier and better-known work of W. S. Jevons.

In France Emile Durkheim's dynamic density is a vaguer repetition of Carey's distance-population relation, and another part of his shrewd analysis is very suggestive of a temperature-like factor in culture. In Russia the premier chemist and industrial consultant, Mendeleyev, turned in the last years of his life to the examination and digestion of social statistics. He defended the concept of the centre of population and determined its position in Russia at the census of 1897. When a chemist of his standing turned to the study of human relations it was an important event; even today a translation of his 1906 book would be highly desirable.

This incomplete list of early contributors to social physics extends into the early 1900's. It contains three astronomers, but (except for Laplace and Gauss in relation to mathematical statis-

tics) no physicists nor mathematicians. At the present time many applied mathematicians are giving attention to the subject of human relations but physicists still stand aloof, although there are exceptions, among whom P. W. Bridgman is outstanding. Perhaps the fact that physicists can always speed their progress by controlled laboratory experiments, while astronomers have to wait for the slow accumulation of observations of the independent heavenly bodies, is what makes the former too impatient to look into social phenomena.

Even today, when the implications of nuclear energy have forced American physicists at last to recognize the social impact of their science and technology, they do not direct their attention toward improving the methods and logic of the social sciences. Instead, numbers of them have banded together in politically naïve groups meant to influence public opinion, regardless of the lack of adequate social principles on which to base their action. This is a strange inconsistency for men who in their own specialities are constantly thinking about, and applying, natural laws.

On the other hand the applied mathematicians have been for some years tending more and more to give attention to problems of social relations. But their labours represent further useful specialization of knowledge rather than the permeating synthesis which so obviously is needed.

There are journals of econometrics, sociometrics, psychometrics. Quantitative studies are accepted in philology. There are inductive and deductive studies of the process of learning. Communication theory, created principally by telephone engineers but initiated by Francis Bacon for the visual semaphores of the early seventeenth century, ties in with the expanding art of data reduction and automatic computation. Matrix algebra finds applications to problems of the stockroom clerk and the programming of industrial operations. The "logistic" curve of population growth is being given additional social applications. Processes by which a group of people arrive at decisions are surveyed and recorded in specially equipped laboratory rooms. Measures of public opinion and of the impact of advertising are being improved. A theory of games has come into existence.

Rather than attempt the severe task of summarizing this vigorous activity we shall indicate the methods adopted in our current Princeton social physics project, and include some of its conclusions. In order to keep the presentation at a non-technical level, all equations are omitted except for a very few which can be described in verbal terms.

AN EMPIRICAL REGULARITY: THE RANK-SIZE RULE

Modern physics had its beginning in celestial mechanics. It advanced through three successive stages, the observational, the empirical, and the theoretical. These are typified by the work of three astronomical investigators: Tycho Brahe, a Dane (1546-1601),

Johann Kepler, born in Württemberg (1571-1630), and Isaac Newton, an Englishman (1642-1727).

Tycho Brahe over laborious years accumulated many reasonably accurate observations of the positions in the sky of the planets, in particular of Mars. Because precise observation was far from being a routine requirement of science at that time, this Danish nobleman was a great pioneer. Kepler became his secretary and inherited his sheaves of observations. Kepler deserves an even higher place among the founders of modern science than he is usually accorded. He had a fanatical faith in number as a means of insight into physical phenomena. To modern scientists that seems no faith but obvious common sense—until someone suggests that number is equally important for social phenomena! Kepler made trials, errors, retrials—many of them "cock-eyed"—before he succeeded in stating the last of his three "laws" on the orbital motions of the planets.

These are not general laws of nature but empirical statements of mathematical regularities which apply only to planetary motions. But when Newton sought to reduce all motion everywhere to orderly description, he needed only to think of Kepler's short mathematical statements, instead of having to essay the impossible task of carrying in mind many thousands of separate measurements. Newton, because he was "a giant who stood on giants' shoulders", carried mechanics without much trouble to its third stage of rational interpretation of all known motions.

The phenomena with which social physics must deal are less tractable, and more intricate, than the harmony of the spheres. This is partly because we view them from the microscopic rather than the macroscopic level, being ourselves "molecules". What the student of the kinetic theory of gases calls a minor fluctuation in pressure may represent a terrific series of bumps to a lot of molecules.

In the modern study of society, no single individual has been a Tycho nor a Kepler, and no one investigator is likely to repeat the role of Newton. Thanks to the labours of the social statisticians, however, the Tychonic stage is unmistakably here. And the other two are in progress.

The available numerical data on society include censuses of populations, vital statistics, tables of geographical areas and distances, rents, prices, wages, dividends, interest rates, studies of business cycles, public opinion polls and psychological tests relating to social behaviour. So far only a very small proportion of this grand observational array has been reduced to concise mathematical regularities.

Outstanding are the brilliant contributions of the late George Kingsley Zipf, of Harvard University, who assembled many regularities in graphs and tables in his 1949 book, *Human Relations and the Principle of Least Effort*. He emphasized particularly a formula known as the rank-size rule, which is followed again and again by very diverse sorts of numerical data. It is worthwhile to give here several of these results, but a non-mathematical reader

who finds the repetition tiresome may skip rapidly through them.

The rank-size rule seems to apply in cases of free competition, for example to the populations of United States cities as determined in every one of 17 decennial censuses beginning in 1790. Presumably each city competes with all the others in attracting and holding residents. It is easy to understand how this rule is derived. Begin by arranging all the cities in order of size starting with the largest. For example in 1940, New York with 7,450,000 people in the central city (five boroughs) ranked number 1, Chicago with 3,400,000 was rank 2, Pittsburg with 670,000 rank 10, Louisville with 319,000 rank 25, Nashville with 167,000 rank 50, Utica with 100,000 rank 92. The city of rank 199 had 50,000 people, rank 412 had 25,000, rank 1,077 had 10,000, rank 2,042 had 5,000, while the smallest place classed as a city, rank 3,464, had 2,500. The late Alfred J. Lotka, actuarial mathematician, was one of the first investigators to notice that the product of the rank by the population is roughly a constant in this list.

We note: New York, 1 times 7,450,000, Chicago, twice 3,400,000 or 6,800,000, Pittsburgh, 10 times 670,000, or 6,700,000; for Louisville the product is 7,975,000, Nashville 8,350,000, Utica 9,200,000; at rank 199 it is 9,950,000, at rank 412 it is 10,300,000, at rank 1,077 the product is 10,770,000, at rank 2,042 it is 10,210,000, at rank 3,464 it is 8,660,000.

Although the range in size and rank is 3,000 to 1, the variation of the product is confined within a ratio of only about 8 to 5. This is what the physicist calls an empirical regularity—one which is observed but for which no theoretical explanation is as yet known. Many social scientists are not yet trained to recognize the significance of the empirical; they demand theories too soon. The rule just described can scarcely be accidental. It must be a consequence of deeper and more abstract principles which come into play in competitive situations. To discover these would be very useful.

Just this same rule—that the product of rank by size equals approximately a constant—appears again and again in social statistics which describe very different competing agencies. Consider the gross business of retail corporations. The National City Bank in a "Monthly Letter on Economic Conditions" ranked the 100 retail trade corporations which in the year 1948 had more than $25,000,000 gross sales. Number 1 was A and P (Atlantic and Pacific Food Stores) with sales of $2,837,000,000 in its more than 3,000 stores. Number 2, Sears, Roebuck and Co., sales of $2,296,000,000. Rank 10, May Department Stores Co., $407,000,000, rank 25, Gamble-Skogmo, Inc., $152,000,000; the corporation of rank 50 sold $69,000,000, rank 100 sold $25,000,000. The product of rank by sales for every one of the 100 corporations is between $2,500,000,000 and $5,000,000,000, a ratio of 2 to 1 as compared with a range in sales of 113 to 1. A few corporations which should have been included in the list published no figures; inclusion of these would have increased by a little all the rank numbers cited after the first ones, but this if anything would have improved the accuracy of the amazing rule.

The rank-size rule is not at present derivable from general principles, and requires much more study before it will lead us to its underlying rationale—which then would fairly claim the dignity of being a law of social physics. Since it holds in such a competitive situation as city sizes, the reverse statement is plausible—that wherever it is observed we may conclude the competition is in large measure free and fair. Thus no one would assert that unfair practices occur when words in an author's potential vocabulary compete for his attention as he scribles along. Several investigators have reported that the rank-size rule is observed to apply here with respect to the frequency of words.

Concentration at the top is a corollary of the rank-size rule; thus 27 per cent of all the urban population in 1940 lived in the biggest 0.3 per cent of United States cities (the leading 10). There is talk of New York's being too big. There was the same talk about London in the days of Queen Elizabeth, when English national planners inspired a proclamation which forbade the building of new houses beyond the tiny limits of the ancient Roman walled city. The demographic tide was not restrained by this paper mandate.

The rank-size rule applies to business establishments when ranked by the number of paid employees in each. According to Department of Commerce statistics, there were 225 firms in 1948 which employed 10,000 people or more, so the 225th in rank by number of employees may be assumed to have had just about 10,000 employees. The product of rank 225 times number of employees 10,000 was 2,250,000. There were 3,100 firms which employed 1,000 people or more (product 3,100,000); 6,500 which employed 500 or more people (product 3,250,000); 35,100 which employed 100 or more (product 3,510,000); 74,400 which employed 50 or more (product 3,720,000); 195,800 which employed 20 or more (product 3,916,000); 505,600 which employed 8 or more (product of 4,044,800); and 1,011,600 which employed 4 or more people (product 4,046,400).

One notes here a small but steady tendency of the product to increase toward the bottom of the sequence. In its more general case, as here, the rank-size rule is modified by raising the rank to a certain constant power before multiplying by the size. If we adopt the exponent 0.92, applied to the ranks in the sequence just quoted the product is made stationary.

Again, retail stores, whether independent or part of a chain, may be ranked by gross sales as individual outlets, instead of by single ownership as in the National City Bank figures. Data are from the 1939 *Census of Retail Trade*. We find that in this series, a constant product is approximated when 0.75 is taken as exponent of the rank. That is to say, the rank of any store to the three-fourths power times the gross annual sales of that store is constant for the series of all separate stores.

The Italian sociologist Pareto a number of years ago found that if all incomes in a country are ranked before taxes, the exponent for the rank, required to obtain a constant product when multiplied by the income, is roughly 1/2. The square root of the rank of

the individual income times the dollars of said income is roughly constant throughout the whole series. This rule has held in the United States for many decades. Although this rule for incomes has long been known, economists have done little with it. Sir Ernest Benn featured it in his book, *Confessions of a Capitalist,* stressing the interdependence of all earners of income.

There seems to be almost no end to the variety of sequences to which the general rank-size rule applies. Rank raised to the *n*th power times size is roughly constant, the exponent also being constant for the given sequence. In word-counts and the like, frequency of occurrence represents size in the formula. In many cases *n* is unity; often it is smaller, and only a few cases have been observed where *n* is greater than unity.

Additional, previously unpublished examples follow. The *American Oxford Atlas* (1951) lists 734 cities in the world having estimated populations about 100,000. These fit the formula if *n* is taken as 0.73, whereas in the 1930's there were something like 601 such cities and *n* was published as 0.77. From other perhaps analogous cases there are indications that such a decrease means a less well integrated competition. In both years the number-one city (London) deviated seriously by being "too small".

The rule cannot be expected to hold for cities in an area selected at random, such as a single state of the Union or a single country in interdependent Europe. However, suitable districts can by trial be found in the United States within which it holds; the most notable example is the area between the Rockies and the Appalachians, which contains half of all the cities. In this area (1940) Chicago was first in rank, although only second in the national ranking; Detroit second instead of fourth; Cleveland third instead of sixth; St. Louis fourth instead of eighth, and so on. Canada also has its own sequence, although its leading city, Montreal, would be only sixth in a joint ranking with United States cities.

An oddity of the rank-size rule is its application to prizes offered in contests and lotteries, where it is observed to be roughly followed in many instances.

A correspondent suggested that the rule might apply to the shattered fragments of a piece of glass. Miss Martha Roberts, of our project, systematically broke 30 panes each 3 inches by 8 inches. A one-inch steel ball was dropped, always from the same height, by burning a suspension thread in order to avoid spin. It hit the centre of the pane, which always broke into two symmetrical halves with eight or 10 pieces in each, not counting the powder at the exact point of impact. Each fragment was weighed and assigned its corresponding rank among the eight or 10. Finally average weights (sizes) were found for each rank. Statistical stability was attained with results from as few as 10 half-panes, in that plots on log-graph paper yielded about the same smooth curve again and again with successive sets of 10.

The curve was convex upward—the smaller pieces were too small to obey the rule with any *n*. Measurement showed that the smaller pieces tended to come from areas relatively close to the

point of impact. It could be said that they were not in "fair" competition with the bigger pieces, as being restricted on the average to the smaller central regions. A plausible correction for this difference raised the lower sizes, straightening the graph and permitting the rank-size rule to apply; but not much value is to be attached to this little exercise as yet. We know of no sequence in the unorganized inorganic world to which the rule directly applies.

The reader who is innocent of any training in natural science may be altogether unimpressed by the widespread occurrence of a mathematical regularity for which no explanation is known. What does it mean? he asks. Of what use can it be? One can only reply that it is from just such seemingly trivial acorns that oaks of science have grown to reach beyond the sky. It has been a leading weakness of training in social studies that adequate attention is not paid to the value of the empirical regularity. Collection of regularities for their own sake has often in natural science been the indispensable step toward later theoretical understanding.

"The cubes of the distances from the sun are proportional to the squares of the periodic times." That was Kepler's third empirical regularity, and to distil it from Tycho's measurements of the positions of the planets took him much time and labour. Engineers daily continue to change man's physical environment by virtue of discoveries which in course of the centuries were fed from that root. The enthusiast who first showed that number had so great a role to play in the physical world was justified in his ecstasy when at last he announced his last rule: "What I prophesied 25 years ago . . . at length I have brought to light, and have recognized its truth beyond my most sanguine expectations. . . . Nothing holds me; I will indulge in my sacred fury. . . . If you forgive me I rejoice; if you are angry I can bear it; the die is cast, the book is written, to be read either now or by posterity, I care not which."

THE DEMOGRAPHIC FIELD

Social physics describes mass human relationships in physical terms, treating large aggregations of individuals as though they were composed of "social molecules"—without attempting to analyse the behaviour of each molecule. It is a paradoxical thing that this seemingly brutal mechanical approach leads to a greater stress on the relationships of people with people than some conventional treatments which are motivated by the usual obvious humane sentiments. The latter are likely to stray off into the relations of dogma with dogma.

It has been well said that people of limited background are interested only in personalities. Moderate experience leads to interest in events. Only a high culture joins to both of these a concern with ideas also. The theories of physical science accustom their practitioners to ideas which have a high degree of abstraction and a correspondingly high degree of power. One such set of ideas

relates to the concept of the field—gravitational, electrical, or magnetic.

For many sociological purposes it is useful to postulate that any cluster of people possesses such a field, the "demographic field". It extends throughout the area which they occupy, and, losing intensity as distance increases, throughout the surrounding area even though empty, and—weakly—to the ends of the earth. Thus the fields produced by all the people are intermingled at all points, but those of the distant people relatively so little that often they can be neglected.

Of course the demographic field has no more than a statistical sort of existence, and becomes a smooth mathematical thing only when the effects of many people are averaged through a considerable period of time. Even then it describes actual human interrelations only approximately, deviations as large as 30 per cent from calculated results being common. Many principles of physical science which exhibit equally large tolerances are considered useful.

When one aggregation of people is placed close to another each is subjected to the other's field, and the result is a strong interaction between the two clusters. It may take many simultaneous forms. Where the people are alike, as within the United States, there is a mutual tendency to closer approach. Thus a highway between two nearby cities becomes heavily populated.

In many instances the interaction can be measured—the number of telephone calls interchanged, or passenger automobile traffic. The number of calls or cars in a given time will be found, on the average, to be proportional to the product of the two populations divided by the distance separating them. The resulting quotient may be called the mutual demographic energy.

If one of the "aggregations" consists of a single person only, the energy, by the formula, is equal to the population of the large one divided by the distance away of the single person, and is called the potential of population at the point in space where that person happens to be. Thus the potential, at a point which is produced by a population P at a distance d from the point, is P divided by d. It is a measure of the demographic field at the point.

It follows that if Q people are at a place where the total potential produced by all other people is V, then their contribution to the demographic energy is half the product of Q by V (because its other half must be assigned *pro rata* to the other people).

These equations were in the beginning discovered by direct observation, as empirical formulas which fitted facts. They are similar in type to the equations of the field in physics, and may now be considered to have a theoretical standing.

One or another of the equations were discovered more or less independently by half a dozen investigators, beginning, as already indicated, with Henry C. Carey. They were first given complete expression in the Princeton social physics project. To exhibit their observational support requires a paraphernalia of mathematical symbols, graphs, and numerical tables which are simple enough

to a physical scientist but out of place in this article. Reference may be made to Chapter 2 of *Theory in Marketing,* edited by Reavis Cox and Wroe Alderson, and published in 1950 by Richard D. Irwin, Inc., in Chicago, Illinois. It contains a bibliography.

Density of population is a physical quantity already familiar in sociology; it is the number of people divided by the area they occupy. Demographers had never introduced a term to measure the influence of people at a distance, which is what the potential does; nor had they analysed the wealth of observed data which show that such a term has meaning and usefulness.

From the census and the map, contours of equipotentials can with some labour be computed for the United States or other areas. This was first done at Princeton, and observed statistics along the contours afford additional strong support for the concept of the demographic field.

Every city is a local maximum of density and of potential as well. Maps constructed of all leading areas in the world—Europe, China, Japan, the United States, South America, and so on—show that each has a major peak of potential at its principal metropolis. Thence, average potentials decrease in every direction, and so do the statistical activities of the people.

Within a great metropolitan area which has numerous settlements of large population density interspersed with scantily inhabited districts, the contours of potential are intricate—and so is the distribution of traffic, land values, etc. But far from cities, in rural counties, the contours run smoothly, and demographic and economic conditions likewise tend to vary only gradually when averaged from county to county.

A study of conditions in the rural counties in the United States has led us to the introduction of another physical analogue, the "social temperature", or level of activity. Provided that a given rural region is not being subsidized by a governmentally-imposed flow of money or money-equivalent from the richer and "hotter" cities, the social temperature of the rural county is theoretically proportional to its potential of population. As the latter can be computed from the census and the map, we can construct a scale of social temperature by using this proportionality. The theory applied is the same as that employed by Emden and Eddington in the elementary model of a gaseous star contracted by its own gravitation. Application to the social problem can be regarded as validated by the observed statistics.

A little restatement and summary at this point will make more evident the necessity for introducing the concept of social temperature. Distance has an inverse effect on relations of people to people—this has been proved by unchallenged analysis published over a period of many years by several independent investigators. Data examined include the relative fraction of students who come from far away to attend a college, newspaper circulations, telephone calls, passenger motor traffic, bus and railway travel, the interchange of telegrams and of mail, the flow of bank cheques, visitors to a fair, registrations at hotels, and even the issuing of

marriage licences and the occurrence of obituaries. This being the case, a county in New Jersey or Connecticut, which of course is closer to more people than a county in, say, West Texas, can be expected to show statistically greater activity on the part of its residents. Observation shows that this is exactly what happens. There are many more people per square mile living in the eastern rural counties, land values and rents are higher, bank deposits *per capita* are greater and so is the percentage of workers in manufacturing industries; mileage of railways and highways per square mile of area is also bigger. Since all these things are thus observed to rise together as the potential of population rises (outside all cities), as we follow the statistics across the map toward the major U.S. potential peak at New York City, the idea is forced upon us of a general equilibrium of the activity-level in a particular rural region anywhere.

One knows that a rich nation might establish a small colony on a distant Pacific island and by continually feeding into it energy of all sorts maintain there a level which would match or exceed New Jersey's. Under these conditions of external subsidy a high activity could be maintained even though the potential of population was low. Therefore we need a separate physical term to represent activity. In physics, temperature is the term which *par excellence* refers to a general equilibrium of activity. So here we need to bring in the social temperature as a measure of the level of activity.

Within any large city, one repeats, conditions are too complicated for easy initial analysis. Hence we had to begin with rural areas, where the study quoted was made with the assistance of Catherine Kennelly Wall and Edith Bissett, (whom Dr. Walter W. Stewart of the Institute for Advanced Study generously assigned to our project). Of course there are local causes which result in deviation from smoothness even in rural counties. A leading example is the district in New Jersey known as the Pine Barrens, where activity is low although potential of population is high. Positive instead of negative deviations are found in a state like Iowa, where the fertility of the land is especially good.

When the potentials produced by people of different sorts are computed, it is necessary, for comparability of results, to make the formula (population divided by distance) include a weighting factor or "molecular weight" by which each population is multiplied. Even within the United States the evidence requires a range of more than 2 to 1 in the molecular weight in different parts of the country. Although numerical data are not available it is certain that the relative influence at a distance produced by primitive savages is very much less than that of people in an advanced state of material civilization. Indeed it was just this disparity of weighting factors which permitted European nations to colonize the other continents, because it increased their influence in ratio to that of the natives enough to compensate for their great distance.

Tentatively the mass of goods *per capita* may be adopted as the molecular weight. This is discussed below as the "social mass *per*

capita", and differs over a range of tens of thousands to one as between civilized and primitive peoples.

A barrier such as a severe international frontier can reduce the interaction of two aggregations of people far below the formula value; but such a political barrier is a line of strain, and can only be maintained by some overriding force. A physiographical barrier, like a mountain range or a broad river, likewise reduces interaction. It, too, is a line of strain, and when the two separated populations become large enough they will "spark through" by constructing tunnels or bridges.

In his *Pure Sociology,* Ward italicized the remark that "in the complex sciences the quality of exactness is only perceptible in their higher generalizations". The concept of the demographic field, with its related formulas, is a high sociological generalization which is validated by a very considerable body of observed social data. A variety of relevant applications suggest themselves—to the historical study of the rise and fall of empires, to the establishment of a world authority, and so on. These may require extrapolation of the theory beyond the scope of its present observational base. And so we pass from inductive to deductive social physics.

Experience in physical science has taught that many of the deductions will be adapted to testing, by comparison with new or old observations. If the theory is to inspire confidence it will have to fulfil successfully each and every such test.

Deductive systems have been all too common in social science, but no previous example has been founded on so much numerical data. On the contrary, a frequent practice has been to start with introspection and take one's own actual or possible personal motives as a model for a standard man. Then comes the greatest fallacy: the attribution to a million men of the character which has been assumed for the one standard man. The spaces which separate people are airily ignored. The manifold differences among them, systematic and random, and the locally-caused cross-currents which always break the parallelism of their movement even when they are exhibiting their greatest unity—these too are ignored. The false equation that one million equals one is all that the mathematical reasoning of many reverently quoted authorities amounts to.

But if social physics, as a deductive system, is to "cover the waterfront" of all of social science it needs to be expanded much beyond the state to which this discussion so far has brought it. The attempt to do this will next be described.

THE DIMENSIONS OF PHYSICS AND OF SOCIETY

Having begun with an inductive approach, seeking regularities without any presuppositions, we have been led step by step to recognize that distance, time (which is obvious), mass, and a factor like temperature are important social quantities. But these are

four of the six fundamental categories of physical science also—as outlined below. The remaining two are electric charge (positive and negative) and, for chemical studies, the combining weight—which is closely related to the number of molecules in a reaction. The six—distance, time, mass, temperature, electric charge, and number of molecules—may be interpreted as the "dimensions of physical science".

A fifth principal social factor has been featured in this discussion—the number of people. It can be taken as corresponding to the number of molecules in chemistry and kinetics. If, finally, a social quantity corresponding to electric charge can be described, we shall have mentioned six leading social factors resembling those of physics; these may well be called the "dimensions of society".

Professor Stuart C. Dodd, sociologist at the University of Washington in Seattle, was the first to work with social dimensions, though he did not try to make a definite list of them. He always however included desire as a dimension. Since desire, in the sense of simple hunger, is neutralized by its appropriate satisfaction, it is in this respect like a negative electric charge, while the desirable object possesses the neutralizing positive charge. Tentatively therefore we adopt desire (and equally that which fulfills it) as the sixth social dimension.

This gives us the list: distance, time, social mass, social temperature, desire, and number of people, as the six dimensions or fundamental categories. This list makes social physics in its dimensional structure isomorphic with physical science. The adjective isomorphic in physics and mathematics means that there is a complete and trustworthy analogy between two or more situations. But, if there exists a one-to-one analogy among the dimensions, we are tempted to look for some further correspondences, and to transfer equations from physics to politics—subject always to test by reference to the social data themselves.

To many scholars and research workers this proposal seems radical. Even among physicists the synthesizing strength of the dimensional approach has not been fully recognized. Few working physicists in these days of intense specialization have much experience or interest in thinking about their great science at this high level of generality. Professor P. W. Bridgman is a leader among those who do: his writings on thermodynamics and dimensional analysis, and his philosophy of operations, are well known.

By dimensional analysis is meant the description of the mathematical form which is imposed on all the equations of physical science by the manner in which the choice of the units of measurement affects them. It emphasizes the solution of particular concrete problems, especially in hydrodynamics and certain branches of engineering. Dimensional analysis, however, has not much concerned itself with the question of how many dimensions there are, or whether indeed a definitie answer can be given to such a question, even if limited to the current state of physics at any year. Nor has it dealt with the choice of the best set of dimensions, or leading factors, by reference to which physics as a whole can

be summarized. In conversations Bridgman has been sceptical of the value of extending the physical treatment to include these matters, but as a firm advocate of operational verifications he has to admit that the proof of the pudding will be in the eating.

Let us look at the historical development of physics in terms of the discovery of the dimensions, one by one. Galileo, by concentrating his observations and thinking on matters related to distance and time, established kinematics. Long before that the geometers of antiquity had dealt with the category of distance. Newton, three-quarters of a century after Galileo, discovered mass, completing the deeply impressive subject of mechanics. Black, Rumford, Carnot, Clausius, and William Thomson established the theory of heat with an adequate recognition of the role of temperature. Franklin, Coulomb, Ampère, Henry, Faraday, Maxwell, Millikan made electric charge the key quantity for electromagnetic theory. And Dalton, with his study of combining weights, unlocked the doors of chemistry where even Newton had failed to gain an entrance.

Up to the present all known formulas of physics and chemistry are reducible to the six "dimensions" fundamental for the six branches of physical science just indicated. For measurement of each a separate unit is necessary, which must be selected arbitrarily. For example we have for distance the metre, for time the second, for mass the kilogram, for temperature the centigrade degree, for charge the coulomb, and adoption of the arbitrary number 16 as the atomic weight of oxygen. (If the atomic weight of oxygen were taken as 23.40 instead of 16, every gram-atom of a pure element would contain exactly 10^{24} atoms. That would be a more convenient value for this number, called Avogadro's number, than the present one, 602×10^{21}, but its choice would have been just as arbitrary.)

All the remaining quantities of physics can be derived from the six dimensions as the products of plus or minus powers of one or more of them. Thus area is distance squared, and energy is mass times the square of distance divided by the square of time. Every term which appears in any equation in physics can be so expressed.

It is not necessary to take just the specific six quantities listed; substitution is permissible so long as we have a total of six independent ones. Indeed distance, momentum, and energy are a more elegant triad in mechanics than distance, time, and mass. (This was shown a century ago by Sir William Hamilton, one of the most original of all mathematical physicists, who elevated Newton's disconnected laws of motion into a unified mathematical pattern for mechanics.) And if instead we use electric charge, magnetic flux, and energy, problems in electro-magnetics become isomorphic with mechanics.

In the course of this long development certain quantities—such as magnetic pole, which at first appeared fundamental—were later shown to be derivable from others already listed. Recognition of the conservation and transformations of energy made it needless to take heat as a new thing; it has the dimensions of mechanical

work and kinetic energy. But all attempts to reduce the number below six may be said to have failed.

Unquestionably it was by grasping the fundamental usefulness of distance and time for physical thought that Galileo succeeded in founding physics as an operational science, where Lord Bacon with his unending miscellany of casual observations did not. So, now, in attempting to evolve the science of human affairs, what better can we do than to try the same sort of classification?

Galileo himself did not fully understand what he was doing. The role of physical dimensions was not recognized until Fourier, in the nineteenth century. No new physical dimension has been required in over 100 years. Perhaps in their present difficulties with the elemental corpuscles and with phenomena of the atomic nucleus physicists are approaching discovery of a new dimension.

Passing now to the social dimensions, distance, time, and number of people offer no new problem of definition and measurement, inasmuch as physical distance and physical time are meant. (During the past year Dr. Walter Isard has made an interesting contribution, in bringing formulas of social physics involving distance and number of people into closer relation with standard problems of location in economic theory.)

Social mass can be measured, although to attain precision would be laborious. Social mass means the physical mass (or weight) of all presently used material which has had to be moved or fabricated to be of utility to society. Social mass therefore refers to the bodies of the people and of their domesticated animals, their stocks of harvested food, their clothing and personal equipment, artificial housing, buildings, and ships, plant of all sorts, the weight of material that had to be moved in constructing trails, roadways, railways, mines, harbour improvements, airports, dams. It includes water being circulated by pumps, and the mass of the tilled soil.

Natural resources still in their original state are not social mass —such as minerals underground, untended forests, fish in the sea, water in rivers, and the like. As possible sources of social mass these things are of great social significance. Natural resources are represented in our mathematics by the time rate of replenishment of social mass. Of course all existing social mass is subject to deterioration, and ultimately lands on the rubbish heap. Friction too is very important, because all energies added to the social system from natural metabolism, as well as from fuels like coal and oil, are rapidly dissipated.

A preliminary survey by Messrs. A. Humphreys and G. S. Fox, two Princeton undergraduate students of engineering, leads to the estimate that the social mass in the United States is of the order of at least 3,000 tons *per capita*. By far the greatest portion is the mass of the tilled soil, since an acre-foot of specific gravity unity would weigh 1,357 tons, and there are two or more acres of ploughed land per person. The amount of water being pumped for cities and for irrigation systems is hard to estimate for the country as a whole. When the reservoirs of the New York City water system

are full there are 100 tons per person, but presumably only a small fraction is at any instance under forced flow in the aqueducts. Water accumulated by gravity behind dams is not yet social mass, although the dams are.

The weight of all dwellings may be 20 or more tons *per capita;* material in cities, excluding dwellings, weighs at least as much again; railroads with their roadbeds and rolling stock account for two tons or so *per capita,* the merchant fleet and navy for a little more, highways perhaps for as much as 125 tons, dams and levees for an estimated eight, poles and wire for little more than one, automotive vehicles for more than half a ton *per capita;* and other highly fabricated products weigh at most a ton or two for each person in the nation.

We have examined statistics for selected nations with a view to arranging them in order of decreasing social mass *per capita,* thus providing a tentative scale into which other countries can be fitted. An example of such a series might be, United States, France, Bulgaria, China, Afghanistan, and the aborigines of Australia. Conversation with the noted anthropologist, Margaret Mead, suggested that for those Stone-Age Australians the social mass is at most a couple of hundred pounds *per capita.* Eskimos who live in Thule, Greenland, possess an average four tons apiece, including of course their housing, according to an estimate by George D. Ecker, Jr., another Princeton undergraduate. Statistical studies sponsored by the United Nations are vastly increasing information of this sort.

This 30,000 to 1 spread in the weight of the social molecule is accompanied by a great range in the number of different occupations—Emile Durkheim's "division of labour". The branch of physics called thermodynamics has a term, "degrees of freedom", which is handy here. It means the number of different ways in which a molecule can exhibit energy. The number of skills possessed by an individual, or social molecule, presents a close analogy; and so social physics interprets the division of labour as relating to the degrees of freedom. An underdeveloped people, struggling for the necessities of bare survival, cannot supply the apparatus, nor spare the workers, for occupations which are a commonplace in better provided nations—that of dramatic critic, for instance, or electronic technician.

A positive correlation is obviously to be expected between social mass *per capita* and the division of labour. It is clear, however, that a society might be rated as barbarian which had great social mass and many occupations—for example, if the mass was predominantly in military equipment, and if scientists, humanists, and artists were lacking.

At this point, therefore, the following conclusion is indicated: civilization requires certain occupations having what we may consider to be a specially high quality. This quality coefficient in turn seems to have a close relation to communication among people—one with another and with their entire environment. The callings of scientist, philosopher and artist are examples. Even where persons are present who have full training in these professions, the

level of social activity may not be high enough to favour free and complete exercise of them. For example, in a crisis of famine almost everyone is likely to be fully engaged with more immediate jobs.

A physicist would expect that at a moderate social temperature most of the usual degrees of social freedom per person would tend on the average to be equally energized, each displaying roughly equal activity capable somehow of objective measurement. The corresponding conclusion in statistical mechanics is Boltzmann's "Equipartition theorem". But those activities of a physical molecule which involve high frequencies of oscillation do not share in the equipartition. According to quantum theory, which is fully confirmed by observation, they display practically no energy until the temperature is raised still more.

These results in physics parallel the difference in society observed between Main Street and the metropolis. Yet so many worthy authors and their readers have been pained by this mathematically predictable difference! (If proportionality with potential of population holds, the social temperature of rural districts in western Texas or Nebraska is four times less than that of rural counties in New Jersey and Connecticut.)

A speculative case can be made for the proposition that the quality coefficient for a given occupation may be simply the maximum frequency relating to the activities which are required to carry it on. Thus consider the series of job classifications: typist, secretary, executive secretary, manager. It lies within the present powers of technology to build a robot photoelectric typist which could copy a printed page at a speed equal to that of a trained girl. If a superior robot could be designed to type just as rapidly while correcting misspelled words in the original copy—as a good secretary should—a higher frequency of operation, or "band width", is required. This is because the machine would have to make continual comparisons with its own stored vocabulary. And if a boss robot could be made it certainly would have to be designed with a higher band width still, because of the range of comparisons it would be continually conducting with respect to a really big lot of stored information.

Any student of elementary quantum physics remembers that, unless the temperature is sufficient, high-frequency degrees of freedom are not activated at all.

While the social mass *per capita,* and the power consumption *per capita* (which is no doubt correlated with it) are greater in the United States than anywhere else, and while the wide-ranging and rapid movement of the people here indicates a high social temperature, it is possible that the older cultures produce relatively more individuals with the large band widths which are requisite for intense communication. A philosopher who sits in a corner and thinks must, if he is successful, possess a far bigger maximum frequency in his internal robotry than a frenzied executive with five telephones.

The dimension of number of people refers particularly to

phenomena of aggregations of individuals. It is the dimension that is specific for social chemistry, just as the number of molecules (which may alternatively be represented by combining weight) is the specific dimension for chemistry itself. There are social bonds which are like chemical bonds. The latter are supposed to be of electromagnetic origin. The student of human aggregations and organizations might look for explanations of social bonds to a psychology patterned on the theory of electricity and magnetism.

Just as an atom may pop in or out of various molecules in succession, so a man may take on this or that social role. Each role has its associated particular social "material". The law of mass action in physical chemistry describes how the aggregation of molecules is favoured by large density and low temperature, as well as by large heat of formation. (The latter refers to the energy released when atoms combine in an "exothermic" reaction. In an "endothermic" reaction heat is absorbed instead of being liberated.) If phenomena of this character can be detected in society, our dimensional thinking receives that much additional confirmation. They can be detected, we suggest, and in important instances.

The recent British election furnishes a striking example of how a small density of population favours so-called individualism and disfavours the bonding between social molecules which is characteristic of collectivism. The Conservatives, with slightly less than 50 per cent of the total vote, carried 96 per cent of the area of Britain, comprising most of the rural and the isolated constituencies.

The politico-economical concept of liberty does not relate directly to the division of labour (degrees of freedom) but to the "social entropy". This is a quantity even more deeply abstract than the social temperature. It refers to the number of different arrangements of the social molecules that leave the assemblage or community unaltered as respects the macroscopic variables, which may be taken as the social temperature and the population density.

At any rate in the simpler communities, such as rural ones, the social entropy, if the physical theory can serve as a guide, increases with the level of activity (social temperature) and with the number of degrees of freedom per person. It tends to decrease as population density rises.

In this paper, treatment of the suggested dimension of desire has been entirely omitted. Our work on this especially difficult phase is only beginning, and a sounder report can be made later. It seems to be true that phenomena properly classified in this branch have aroused more of the interest of sociologists than all the rest of their subject, and the attempt to find a measure for desire is far from new.

Thus although many difficulties and hazards remain to be overcome, we see that social physics promises to supply a frame of reference general enough and precise enough to make effective a variety of new co-operative researches. Scores of social terms and processes can be assigned counterparts in physics. Although social physics eschews the superficially appealing method of anecdotes

and personal emphases that is the stock in trade of the older schools of social science, it is a humane and synthetic way of thinking, capable of touching and illuminating most if not all of the social disciplines.

NATURAL LAW AND SOCIAL ENGINEERING

During the year 1951 the Princeton social physics project was host to two conferences, and benefited by attention and criticism from authorities in the following fields: administration, advertising, anthropology, astronomy, biology, business, chemistry, city planning, demography, economics and econometrics, engineering, geology, geography, history, law and jurisprudence, mathematics, philosophy, physics, political science, psychology, public relations, religion, sociology, statistics and theology.

General as is the dimensional treatment, this list will make it clear that we have been interested in projecting our subject on a philosophical canvas which is even broader. One purpose of such wide discussion is to reveal and soften objections that can be advanced to a mathematical science of human relations.

For example, there is commonly exaggeration of the accuracy required for the type of methods used in physics. True, a few quantities in nature have been observed with the enormous precision of one part in 100,000,000, and many to a part in 1,000,000. But some measures in chemistry and physical chemistry have not even an accuracy of one part in 100, while in astrophysics there are determinations which are uncertain to a factor of two or even of 10.

In social science, census counts of population have been tabulated to nine-place accuracy but are uncertain by at least one per cent. In economics a false impression of accuracy is often given in estimates of national income and cost-of-living indices and the like; although the errors are doubtless several per cent, these data are published to three or four significant figures, thus giving the impression that they are accurate within, say, 0.1 per cent. It is certain that the social field abounds with measurements which are quite accurate enough for physical treatment. With respect to regularities which have been mentioned earlier in this discussion, their agreement with observed numbers is in many instances closer than a factor of four to three, which can be regarded as a satisfactory tolerance in the initial stages of social physics.

Comments of a different sort come from humanists, exponents of man and his supposed freedoms, who are already disconsolate over technology's explosive expansion. To some of them the idea that modern mathematical methods extend into any parts of their antique and cherished preserves is very unattractive. A few are stubbornly oblivious to all evidence that men in the mass follow on-the-average regularities resembling the ones in physical sciences for matter in the mass. They insist upon thinking of the interactions of millions of people in unquantified personal terms

which are suitable only for the relations among a few people. They are likely to declare that physical determinism in crowd behaviour would necessitate a philosophy of fatalism.

Their murmured appeals to "value judgments" and "normative principles" sometimes replace hard, connected, progressive thinking. To artists and physicists matter has a function that has been well described by Sir Edmund Whittaker as "sacramental". But plenty of influential wordmongers are afraid of matter, and disguise their fear under a smug and vain superiority to laws of material things.

However mistaken such opinions may be, they have been held for a long time by many intelligent people. Therefore social physics can attain wide influence only if its supporters remember that physics too is one of the humanities. Indeed the term "law of nature" is common to natural science and jurisprudence. Ever since it discovered indetermination, an interpretation of physics has been possible which goes far toward reconciling microscopic freedom of individual particles with a high degree of macroscopic determination for phenomena of assemblages of particles. Today's physics exhibits two realms of natural law—the microscopic in the newer quantum mechanics, the macroscopic in the older mechanics of Newton and Hamilton.

May there not similarly exist for human relations the same two realms of natural law and justice—microscopic or personal, and macroscopic, or social? Concerning the former, the social physics we outline has at present nothing new to add to the legal lore of the ages and the moral lures of the sages. With respect to the latter it will, when further tested, have a great deal to contribute.

The historical situation here is of tremendous significance, although ignored by historians of science as well as by writers on jurisprudence and moral philosophy. In an imperfectly developed form the law of nature had held for 2,000 years an important place in Western jurisprudence before Francis Bacon, later Lord Chancellor of England, advocated its application in physics. Greek philosophers like Democritus believed in the deep-seated regularity of physical nature. This belief, Professor F. S. C. Northrop thinks, contributed importantly to the establishment of political law as a general synthetic principle, although in physics itself only minor examples were found before the seventeenth century.

The law of nature in jurisprudence and moral philosophy as discussed by Aristotle and Aquinas retains to the present day a flavour so predominantly moral that it has not invited the elaboration which scientific study could have given it in the modern era. For a century it has been losing ground in Anglo-American legal practice to the doctrine that law is whatever legislators and courts say it is. This definition of John Austin's that "law is the command of the sovereign" is inapplicable for international affairs, where no sovereign exists. Indeed it is dangerously misleading, because, in the intricate and controversial effort to set up an international sovereign, justice is lost sight of. Macroscopic justice is what is needed for nation-to-nation relations.

In natural science natural law has received unceasing development throughout the modern era. It was not given to the brilliant and subtle nobleman Bacon, Baron Verulam and Viscount St. Albans, to establish natural law as a going concern in physics. Although like Democritus he had the grand conception of regularity, and not animistic arbitrariness, in nature, and appreciated, as the ancients did not, the necessity of making observations if its discovery was to be achieved, he never went after the correct basic categories for expression and measurement of physical reality—for revealing the determinism which he knew existed. That remained as we have seen for his contemporary Galileo, a mere foreign professor whom Bacon ignored.

Social physics can be described as the repayment by physics to politics of the borrowed law, with the rich interest earned since the year 1609 when Bacon published *The Advancement of Learning.*

Anyone familiar with the marvellous partnership of the scientist and engineer knows that the seventeenth-century discovery of the determinism of matter has not impeded but greatly advanced human liberties. It is the existence of natural law, above and independent of man and his legislatures and schemes, its discovery by the scientist and acceptance by the engineer, which enables the latter vastly to enlarge man's powers and freedoms, through illimitable technological triumphs. The growing recognition of natural law in social relations will permit the social engineer to match these successes through correct design of institutions and policies.

Among social engineers lawyers ought to be equipped to take a leading part. Dr. Roscoe Pound, now Dean-emeritus of Harvard Law School, gave 30 years ago an interpretation of law as social engineering; but until jurisprudence brings its law of nature up to date, lawyers cannot so function. There is a very important sense in which scientific law, like law for jurisprudence, has a moral implication. An engineer behaves unethically if his designs are not in accordance with known laws of nature, whether he is an engineer of the mechanical or electrical variety or the social. Division therefore cannot be sharply made between scientific law as the "is" and moral law as the "ought". Professor Jacques Maritain, who participated in one of the conferences mentioned above, declared, "Social physics, the knowledge of natural law in scientific terms, may be expected to show that acts and policies in violation of the moral law wind up in failure inasmuch as they lead to unfortunate consequences in social relations among men."

The lawyers who framed the Constitution of the United States were more respectful toward the laws of nature than are lawyers in this country at the present day. Woodrow Wilson pointed out the influence of Newtonian mechanics on their work, but he himself took the lead in modifying the relation of Congress and the Executive in the direction of purely empirical British practice. Although the subject is too involved for cavalier treatment, it may be contended that after the eighteenth century the prevalent

British philosophy of empiricism insulated the British Constitution from strong natural-law influence. The same situation now exists in law schools in the United States, which, without adherence to an overriding formulation of general principles of right thinking, have become trade schools.

It is ironical that, whereas the founding of the United States posed a problem of sovereignty much less complex then than does world regulation now, it was guided by men who revered natural law, which does not base itself on mundane sovereignty; while on the other hand United States lawyers active with the League of Nations and the United Nations have not been trained to concern themselves much with natural law.

Writing recently in *The New York Times,* Mr. James Reston made an excellent statement which may be quoted as expressing the need for a social physics: "The theory that men dominate events does not prevail. All the evidence is to the contrary. In every country those having responsibility are trying to deal with forces that are almost beyond the imagination, let alone the control, of mortal men; and the dilemmas which they face at every turn are stubborn and dangerous."

A critic in the magazine *Fortune,* January 1952, declares that social engineering has reached the proportions of a substantial "movement". Let us hope this is the case, although that particular critic in a mildly satirical way echoes some of the common misunderstandings of it which have been discussed here already.

Many people have heard of "operations analysis". This usually means problem solving by a competent team of workers who bring to bear on a particular situation whatever information can be of aid. They may be preparing the way for executive decision higher up. The wide range of training which the different members possess means that they will not be satisfied with merely conventional solutions. There is no reason other than its expense why operations analysis should not be extended beyond problems of the armed services. In key difficulties of economics and politics the quantities emphasized in social physics are understressed by policy makers.

For example, the foreign policy of the United States for more than 50 years has given insufficient roles to factors of distance, number of people, and social mass *per capita,* and to a formula for social entropy. Statesmen of this and other nations, in their well-intentioned reliance upon the verbal blacks and whites of their particular accustomed village moralities, and with too narrow information about conditions in populous countries physically very different from their own, have embarked upon grandiose undertakings where on physical grounds failure was predictable, and where failure meant that the people perished in vain.

A philosophy which could claim the adherence of social physicists, social engineers, and operations analysts alike might run as follows: Right thinking and right action are always invaluable, but mortal man never attains to perfect absolute ethics, nor absolute truth, nor even to absolute logic. As we gain command of

wider reaches of sciences our ethics can become more consistent and elegant, but neither attainable science nor attainable ethics is ever a complete substitute for the other. Yet as an article of faith some among us may postulate that at the level of perfection, toward which forever we strive, the three—ethics, science, and logic—become one and the same.

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BOOKS AND PUBLICATIONS

OPERATIONS RESEARCH WITH SPECIAL REFERENCE TO NON-MILITARY APPLICATIONS—*A Comprehensive Scientific Aid to Executive Decisions.*

A Brochure prepared by the Committee on Operations Research, National Research Council, Washington, D.C., April 1951.

Operational research, in the modern meaning of this term, was born in England in the early stages of World War II as an aid to the study of military operations. Ever since the end of the war efforts have been made, particularly in Britain and the U.S.A., to apply the techniques of Operational Research to non-military activities. The text reproduced below is an important statement on the subject by the Committee on Operations Research of the U.S. National Research Council.

Operations research (or, as the British say, operational research) is the name of an applied science, extensively developed during World War II in the British and American armed forces. Its subject matter is "operations", in the usual military or management sense of the word.

The earliest efforts of military operations research had short-range aims, such as increasing the effectiveness of early-warning radar net. As operations research proved its worth, its applications spread, in magnitude and scope, throughout the military effort until nearly every arm of the services of the United Kingdom, the United States, and many Empire forces had set up operations research groups. Accounts of these developments are given in several books and articles, with such case histories as security restrictions permit. (A list will be found at the end of the pamphlet.)

In the course of their work, many members of the various operations research groups became convinced that the techniques used are not limited to military applications. They became convinced that *large and complex organizations or activities* are profitable objects, in themselves, for scientific study. This was independently verified by scattered instances of the successful application in business and industry of techniques equivalent to those now known as operations research.

The analogy between military forces and industrial or business organizations is close enough to warrant the assumption that the general principles of operations research, as developed during the war, can be fruitfully applied to business and industrial activities, and to those governmental activities which have an operational character.

The National Research Council, recognizing the great value of operations research, has established a Committee on Operations Research to further its development and application outside the armed forces. A parallel movement was begun even earlier in Britain. British scien-

tists have founded an Operational Research Club, with many distinguished members, to promote the non-military development of operational research. They have also begun publication of a journal, the *Operational Research Quarterly.* [8] [1]

The Committee on Operations Research of the National Research Council has undertaken a programme for immediate action. The steps which are presently foreseen include the sponsoring of conferences on non-military applications of operations research, a survey of existing manpower, formulation of a training programme, and publication of topical and fundamental material on operations research. The Committee will not, however, undertake active operations research, nor serve in a consulting capacity, except in a general orientational way.

Publication of this pamphlet is one step in this programme. It provides a brief description of the main features of operations research, for two audiences: leaders of U.S. enterprise and government, and scientists. The Committee hopes that it will give to the administrative group some notion of how it could be applied to their organizations, and that it will give to the scientists an indication of its principal features without attempting a discussion of techniques. The Committee will welcome questions and expressions of opinion, and will supply further information on request.

WHAT IS OPERATIONS RESEARCH?

Dr. Charles Kittel, [1] of the Bell Telephone Laboratories, defines operations research as "a scientific method for providing executives with a quantitative basis for decisions". Sir Charles Goodeve, [3] of the British Iron and Steel Research Association, adopts essentially the same definition. He characterizes operations research as in essence "quantitative commonsense" and goes on to say:

"The field of operational research depends on the interpretation of the word 'operations' in the definition. In war, operational research was applied to the use of weapons, to tactics, and to strategy. In the peacetime application of operational research, studies are directed, for example, to the use of equipment and manpower, to operating procedures, and to the solution of those many problems faced by management in controlling or operating factories or public utilities, or by Government authorities in planning. The field of operational research is very wide; but it will be seen that it is quite distinct from the field of most applied scientific research, the latter being concerned with new or improved processes, equipment, materials, etc."

Combining various definitions, we may say that operations research is the application of the scientific method, to the study of the operations of large complex organizations or activities. Its objective is to provide top-level administrators with a quantitative basis for decisions that will increase the effectiveness of such organizations in carrying out their basic purposes. Thus, although the activity consists of research, it is research with a severely practical goal.

1. The figures in brackets refer to the bibliography at the end of this article.

But no brief definition can be expected to convey more than a vague notion of operations research, its subject matter, its methods, its distinguishing characteristics, its significance. Examples of typical problems attacked and solved by operations research groups will provide a better basis for understanding. Several such examples will be given, necessarily briefly, in these pages; others will be found in the books and articles referred to at the end of this pamphlet.

WHY SCIENTISTS?

Every definition of operations research, and every illustration of its use, implies that the men who carry it on are trained in scientific method. It is clearly worthwhile to ask whether this is an accidental phase of operations research, or whether it is essential. Operations research in the military field is closely tied to complex and specialized equipment, the use of which demands technical skill. It is not surprising, therefore, that wartime operations research was carried out by scientists. It might be supposed, however, that the analysis required in non-military operations is more general in nature, and that there is no special requirement for scientific training on the part of operations research men.

This is not the case. The scientific training of an operations research worker is essential for two major reasons: First, since the material with which he deals is in many cases of a repetitive character, a good grounding in the essentials of probability theory and statistics is indispensable. Second, a scientific training tends to develop sound habits of observation and experiment, and makes available advanced techniques of quantitative analysis, which give operations research much of its power and fertility.

We believe that in this field a scientist has unique importance because he has learned that whatever his philosophical views may be, he must in his work assume the existence of a concrete external physical reality, and whatever facts or theories he encounters must relate themselves somehow in his mind to this basic reality.

In fact, if the requirement of skilled application of scientific method were omitted from the definition of operations research, there would be little to distinguish it from many existing management techniques. Quantitative bases for executive decisions are a conspicuous part of the material passing across the desk of every major executive in any large organization whatever. The novelty lies in the scientist's ability to use more refined and powerful numerical techniques, and in his ability to penetrate to the essential variables in a situation, and to relate phenomena to them in a simple and cogent manner.

In this connexion, we should remark that very frequently the principal contribution of operations research in a concrete case is to define, or demonstrate the need for, a new measure of performance or efficiency. Such measures provide the executive with new possibilities for control of his organization's activities and for prediction of its future capabilities. The results are sometimes startling in the speed and size of the improvements obtained.

Such a contribution is the result, in most cases, of a thorough theoretical study of the operation in question, combined with some extremely practical observations. For example, some work done on the Royal Air Force's maintenance norms resulted in a very substantial increase in flying hours per month, with no increase in maintenance manpower. The work was done by Dr. Cecil Gordon, a geneticist; but none of it involved principles peculiar to genetics. Rather, Dr. Gordon's training in genetics had developed in him broad scientific habits and techniques, which he applied easily and effectively to this practical problem of maintenance scheduling.

A similar example is that of a study of the difficult problem of determining the pulling power of certain important types of department store newspaper advertising. The problem here was to determine whether the store *as a whole* increased its sales and profits through such advertising. This study was carried through to actual numerical solution; in this case, the work was done by a theoretical astronomer.

Many other examples will be found in accounts of operations research, testifying to the transfer value of a scientific training, and to the existence of important and difficult scientific problems in the everyday operations of large organizations which can be solved by these techniques.

WHAT PROBLEMS DOES OPERATIONS RESEARCH TREAT?

There are many areas of executive decision in which the scientific method is inappropriate, or at least incapable of providing a solution, given the present state of knowledge. Logical analysis is not out of place anywhere, but there are sharp limitations on the use of numerical analysis and controlled experiment. Successful management of large-scale enterprises or operations involves, and always will involve, delicate judgments on matters of style, or taste, or selection of key personnel, corporate relationship, ethics, and so on. In these fields, the contribution of operations research will be small, if not wholly absent. Operations research does not supplant executive judgment, but rather supplies precise information and useful principles to aid the executive in making decisions. When operations research does suffice for the full solution of a problem, the executive receives an indirect contribution in addition to the direct one in his increased freedom to devote himself to problems which require the exercise of his seasoned judgment. Responsibility for decision must in any case rest with the administrator.

On the other hand, within the broad limits where the scientific method does apply, every problem is legitimately one for operations research, with only the practical requirement that the solution should contribute sufficiently to the good of the organization to justify the time spent in getting it. The operations research worker is scientific adviser to management on any and all operational matters; his duty is to examine any and all relevant questions. Consequently, it is not possible to state in advance what the specific tasks of operations research will be in any concrete organization or enterprise.

For these reasons, the examples which are given here should be looked on as illustrations only, and not as "boundary markers" defining the limit of operations research. The reader may find that concrete examples of possible operations research will occur to him on the basis of his own experience.

In its military applications, operations research is concerned with weapons, tactics, and strategy, as has already been indicated in the quotation from Sir Charles Goodeve's essay. [3] It is not difficult to construct analogies to these three divisions of effort, which can be used in discussing non-military applications, and it is therefore useful to consider the military applications first.

Operations research began with a study of radar, taking up such questions as location of antennas, efficiency of operation, and interpretation of signals. Goodeve credits radar with having multiplied the British power in air defence during the Battle of Britain by a factor of 10, and credits operations research with a further doubling of the effectiveness of the air defence system. As he remarks, the latter contribution was the work of a half dozen scientists attached to Fighter Command; the result was "out of all proportion to the amount of effort spent on the research".

Later, operations research workers made a close study of the use and the design requirements of depth charges, anti-aircraft guns, naval mines, and so on. An extraordinarily brief operations research study showed, for example, that if the explosion depth of depth bombs were modified, a fivefold increase in the effectiveness of the air anti-submarine forces could be expected. This increase was obtained.

By analogy with the study of weapons, non-military operations research would be concerned, at this first and lowest level, with the study of the use and arrangement of machines, signals, controls, and so on. These machines are studied in their working surroundings, under conditions of actual use, and, directly or indirectly, in connexion with the activities of the whole organization. Two examples of this sort of work are quoted by Dr. W. S. Glanville, Director of the Road Research Laboratory in Britain: one concerns the effectiveness of pedestrian crossing marker systems, and the other a study of laying road surface materials. Dr. Glanville puts the annual savings resulting from the second study at a million pounds sterling.

American industry, as is well known, has worked long and hard on the design and use of machinery, and this fact may make it appear less likely that further major economies can be developed. History tells us, however, that revolutionary improvements come at unexpected times and in fields that seem to have been exhaustively developed. Putting to one side such major improvements, operations research can add to existing techniques in helping the executive solve the problems presented to him by frequent plant renewal and industrial change. It can help him, for example, to set up measures of efficiency or effectiveness and hence production goals which may be far beyond current norms. And these production goals are frequently attainable when the required changeover of the production process is made. This was the case in the Royal Air Force maintenance problem previously discussed. In this field operations research overlaps industrial engine-

ering and some other disciplines, all having the aim of improving plant efficiency. The difference lies in the method of attack and in its implementation.

The second level at which operations research is effective is the so-called tactical level. According to the dictionary definition tactics is the art of disposing military or naval forces, especially in contact with the enemy. In the air war against Germany, for example, tactical problems included finding the best flying altitude, the best division of payload (among the competing categories of fuel, search instruments, and bombs or other armament), the best methods of attack, and so on.

There is no one best flying altitude, of course. There is only a "best altitude under a given set of conditions". The choice of altitude will depend on the weather, visibility, sea conditions, radar conditions; it will depend on the enemy's lookout effectiveness, aeroplane speed and manœuverability, and so on. Some of these factors change from day to day, others more slowly. Tactical studies have the purpose of establishing quantitative relationships between the various tactics and the over-all result of the operation of which these tactics are components. When successful, such studies lead to predictions of the effect of changing one or more of these variable components. If, for example, the altitude of the aeroplane is increased by 10 per cent, what will be the effect on the efficiency of the search operation? It has been found that studies of this sort, carried out by operations research methods, frequently permit a rapid improvement in effectiveness. In some cases it pays far more to improve tactics than to improve weapons, and it is almost always easier, faster and cheaper to do so.

A second definition of tactics, suitable also for non-military applications, is "a procedure for gaining some end". If we combine this with a rephrasing of the previous definition, we have a good basis for building up non-military analogies: "Tactics is the art of disposing of forces in actual operations according to definite procedures for gaining some end." The actual operations contemplated in the definition may concern production, or sales, or training, or some other activity. The tactical problems might concern the scheduling of processes, or the optimal utilization of plant facilities, or the routing and control of traffic, or the conduct of a sales campaign. As in the military case, solutions of such problems cannot be valid for all times and conditions. The executive who uses them in formulating policies must be keenly aware of these limitations. It is the duty of the operations research worker to see to it that he is, and to furnish appropriately modified results whenever changing conditions make it necessary. Properly executed, these tactical studies can provide administrators with a firm quantitative basis for decisions, whenever such a quantitative basis is appropriate and attainable.

Studies at the first, or material level give rise in a natural manner to studies at the second, or tactical level. Similarly tactical studies give rise naturally to a third type of study—the strategical. Strategy, in the military meaning of the term, is the art of managing armies or other large-scale forces, in such manner as to compel the enemy to engage in battle under conditions favourable to the strategist.

Operations research can help at this level by making rapid calculations of the amount and kind of force required for specified complex operations. Such calculations must in every case be based on a solid foundation of material and tactical studies, which provide the necessary numerical knowledge. An outstanding example of strategic operations research is the work done by British and American scientists on the Bay of Biscay campaign against submarines. Operations research teams designed and helped to execute the "unclimbable fence" patrols, which succeeded in sighting practically all submarines that went out of or came into the Bay. About half of all the submarines sighted were attacked, and of these roughly one-fourth were sunk. This loss was sufficient to force the enemy to modify his strategy drastically, but this did not help him as his new strategy had been foreseen and prepared for.

After what has been previously said concerning the analogy between military and non-military problems at the tactical level, little need be added here about the analogy at the strategical level. Strategy in its non-military sense should include the planning of campaigns, the broader problems of organization, the estimation of plant requirements, studies of plant location, studies of markets, certain aspects of personnel and of labour relations problems, and so on. Large-scale problems of this sort necessarily involve a large number of subsidiary problems that are not amenable to complete quantitative formulation. For the solution of problems of the latter sort, operations research has little to offer, and it is important to the future of this young applied science that its practitioners make clear to those using it that it has the same limitations as does the scientific method in general.

This does not mean that operations research is of no value at the strategical level. It does mean that operations research should be applied only where it is applicable, to those parts of the broader problems which are suitable for a quantitative treatment. Used in this way, operations research will be of signal aid to the administrator by removing certain problems from the field of his attention and by providing him with clearcut numerical data bearing on other of his problems. With these aids he will be better equipped to face the broader strategical problem, with its many intangible aspects.

IS OPERATIONS RESEARCH A NEW FIELD?

One is tempted, at first, to say No. Heiro consulted Archimedes when Syracuse was besieged, and Napoleon made use of technical advisers. Many alert business executives have long used research procedures, not only for their technical problems but for broader aspects of their activities. Quality control, time and motion analysis, efficiency engineering—are these not operations research?

The answer is that they are parts of operations research, but only parts. And it is essentially true about operations research that one cannot subdivide it and still have it. For operations research is more than the sum of scattered activities, even though each such activity is one of its parts.

The things that make operations research an essentially new field are principally these:

1. *Its Inclusiveness.* Operations research deals with problems that are organization wide, and it deals with the *whole* of such problems. It may very likely concentrate study on certain parts, but it does this not because these parts are easy or attractive (which would often be the case in pure science), but because over-all examination has revealed that these parts are the critically important ones. Operations research uses the widest possible set of tools. It may utilize such studies as would be made in time and motion analysis, but it also uses the insights of the statistician, the psychologist, the mathematician, the engineer, the physiologist, the specialist in probability theory, etc., etc. And *it puts all these together,* into one over-all and interrelated analysis.
2. *Its Direct Relation to Management.* Operations research ceases to be operations research if tucked away in some obscure corner of the organization chart. It has to be built in at the top, having unimpeded access to information, having direct cognizance of over-all problems, and having direct relations with the policy-determining and decision-making levels.

The novelty of operations research lies, then, not in the use of certain specialized scientific techniques, but in the broad scientific approach to the problems of the organization as a whole. It lies also in the new conception that emerges of the relationship that can fruitfully be established between management and science. This relationship should be cultivated with skill and tact on the part of both administrators and scientists, in the interest of increasing the efficiency of operating organizations, with consequent economic and social benefits.

It is true that operations research, in the present meaning of that term, was practised by a few trained scientists in widely scattered industries long before its military use. But it required a world war and the emergencies of a Battle of Britain for its independent development as a new applied science.

WHAT KIND OF SCIENTISTS ARE NEEDED?

Experience in military operations research has shown that special kinds of talent and personality are required for its successful prosecution, in addition to an indispensable scientific point of view acquired in one of the sciences. The operations research scientist must have, above all, a flair for the practical, a special talent for sorting out, from all the alluring and promising problems that he encounters, those that have the greatest practical bearing. This means that he must nicely balance the time and effort (and hence the cost) involved in attacking a given problem against the economies to be expected from its solution, at the same time taking account of the likelihood that a solution will be achieved. He must have a personality that will permit him to deal successfully with all ranks in the organizational hierarchy, from top to bottom.

In order for the non-military applications of operations research to

achieve a significant fraction of their potentialities, it will be necessary to provide scientific manpower in considerable quantity. Among the younger scientists and research students there are no doubt many who have the necessary qualifications and who would be attracted to the field of operations research if better informed concerning its nature and the opportunities it offers. One purpose of this publication is to provide such information about operations research. Those scientists interested in more detailed information will find it in the references at the end of this pamphlet, especially in the book by Morse and Kimball. [7]

CONCLUSION

At the present time the military applications of operations research are being carried on and developed by the armed services. The non-military applications, however, have not up to this time received any organized support and encouragement, and continue to be carried on only sporadically in isolated organizations.

It might be thought that at this time, when we live in a shadowland between war and peace, only the military applications of operations research should be cultivated. This is not the case, for two reasons. First, an increase in the efficiency of operating organizations, both industrial and governmental is at least as important during a war, or a pseudo-war, as in times of peace. Second, the expansion of non-military use of operations research will inevitably increase the number of scientists trained in this field, and these scientists will be available to the armed services in case of subsequent need.

In fact, at a time when mounting defence requirements are putting an increasing strain on the economy and its manpower resources, the non-military development of operations research takes on added importance. For to the extent that it is successful in increasing the efficiency of business and industry it will contribute to the easing of this strain.

With this point of view in mind the Committee has outlined a programme of action. It is prepared to promote the establishment of operations research wherever it gives promise of increasing the efficiency of large-scale operations or activities. It proposes to interest, as a first step, a number of enterprises—industrial, business, governmental, or other—in the experiment of setting up operations research programmes, under as ideal conditions as possible. In the setting up of such experimental programmes the Committee will act in an advisory capacity, when called upon to do so, and in particular it will do everything in its power to aid in securing operations research scientists of the highest quality to insure the success of these preliminary experiments. From the longer point of view the Committee hopes to take part in the development, on a scale commensurate with the expansion of the field, of facilities to attract and to train younger scientists, and to carry on research in the methodology of operations research.

The Committee is prepared to act as a clearing house for infor-

mation. Questions, comments and suggestions for the further development of operations research will be welcomed.

Communications should be addressed to: Committee on Operations Research, National Research Council, 2101 Constitution Avenue, Washington 25, D.C.

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"THE STUDY OF INDUSTRIAL OPERATIONS",

by Sir Ben Lockspeiser, *Research*, Butterworths Scientific Publications, London, March 1952, vol. V, no. 3, pp. 97-100.

In the present phase of British economy, when raw materials are scarce and capital investment is severely limited, common sense prompts the question whether full use is made of whatever resources are available in the way of materials, machinery and labour. The answer can be given by operational research—scientific surveys aimed, in this particular instance, at analysing industrial processes step by step in order to increase efficiency in the use of materials, machinery and labour. The author, who is Secretary of the Department of Scientific and Industrial Research, gives several examples of comparative studies of industrial operations in which the DSIR is interested, and shows the extent to which improvements are possible even where operations seem most efficient.

For example, detailed studies were made in the boot and shoe industry, and the results in 12 factories showed very considerable variations in productivity from one factory to another. It was found that if all factories in the group raised the productivity of each department to the level of the three best, the total saving of man-hours would reach 20 per cent. Even greater economy would result if productivity on each operation were raised to the level of the best to be found for that operation. The survey also revealed the influence on productivity

of payment, showing that productivity of day workers is almost invariably lower than that of piece-workers, a fact easily accounted for by the greater incentive which the piece-work system provides. But it was also observed that the work for day workers was rarely as well organized as it was for piece-workers, and the research team concluded that the flow of work and organization had been of even greater importance than incentive in raising the piece-workers' productivity.

Study in the spinning industry reveal an even wider variation in productivity from one mill to another. Yarn count (the number of 840 yard hanks per pound) and the presence or absence of certain optional operations (e.g. combing) had a marked effect on the overall productivity, whereas other factors in yarn specification (quality of raw cotton used and the degree of twist) had not enough effect to be identifiable. Further, by comparing mills making yarns of approximately equal counts, it was possible to deduce a great deal about the relation of machine speed and package size to productivity for a particular operation. Yet when all sources of variation have been eliminated, differences of output per man-hour as great as 2 to 1 can be found between one mill and another. When however the working arrangements of a mill were rearranged so that no individual room had a higher productivity than the best that could be found elsewhere in the industry for a comparable operation—in other words, when the mill had been organized to reach the highest level of productivity in every room—it was found that the productivity was strikingly higher than that of any other comparable mill in the industry.

However, labour productivity is only one of the factors of production, and other indices of efficiency must also be taken into account. A firm or industry, to remain viable, must retain flexibility, and this may easily involve some sacrifice of current efficiency. It may be necessary, for example, to build up reserves of labour, or to use equipment which can be readily turned from one sort of output to another. It is unreasonable therefore to use productivity surveys, especially if they concentrate on one factor of production only, as the only yardstick of efficiency. Their purpose is rather to locate the "weak spots" where slack may be taken up without prejudice to other factors, or to give information enabling the management to set one cost against another.

Other surveys have been concerned with technical, organizational and sociological problems. In the technical field the Wool Industries Research Association has made a study of faults and irregularity in woollen cloth, and has devised means to enable a substantial reduction of yarn faults to be made, with a corresponding saving in mending time.

But ultimately, all scientific investigation of productivity involves human beings. Even where human relations are unusually good, resistances, tensions and suspicions exist, and the systematic study of their causes and the ways of lessening or removing them may be as rewarding as the raising of labour productivity. Such a study might, for example, throw light on the problem of labour turnover in industry. According to a survey made by the British Institute of Management, 20 per cent of men and 15 per cent of women leave during the first

month, and 60 per cent of either in the first year. The wide variation in the figures from firm to firm follows a pattern noted earlier in connexion with industrial productivity and provides the opportunity for the same kind of comparative study.

Of special interest are problems regarding machines. Machines are becoming more and more complicated and difficult to control, contributing as much to fatigue as does sheer muscular effort. It may be that, in the field of engineering design, something more is required than a reduction of pure physical effort by the operator—for example, the design of machines better to suit the people who work them. Here, too, operational research may provide a solution.

"BIOLOGICAL RESOURCES AS A FACTOR IN INTERNATIONAL UNDERSTANDING",

by Karl Sax, *Scientific Monthly*, Washington, D.C.
May 1951, vol. LXXII, no. 5, p. 300-5.

The thesis of the author, professor of botany in Harvard University, is that there can be no firm foundation for international understanding until most of the world's people reach a reasonable level of economic and educational development, and that without adequate nutrition no people can maintain the health and vigour necessary for the economic development of their resources.

Promises of a better life for all mankind are often made without consideration of the population problem—and of the biological resources which must be considered in relation to that problem. Every decade the resources of the world must provide for an additional population equal to that of North America, and the problem is made even more difficult by the fact that the greatest growth is, or is likely to be, in the under-developed areas where living standards are already low. Before World War II, total food production was about 1,000 million tons annually, but two-thirds of the world's people did not get enough to eat. Today the standards are even lower, partly owing to an increase in population of about 10 per cent during the past decade. To attain minimum nutritional standards for the undernourished people, world food production would have to be raised at least 30 per cent above pre-war level. To provide diets in accord with U.S. standards, the world output of food would have to be more than doubled.

An increase can be achieved either by improving the yields, or by bringing new land into cultivation. Yields per acre vary enormously as a result of differences in soil, climate and farm management. Western Europe produces three times as much food per acre and eastern Asia twice as much as the United States and Canada. Japan's production per acre is twice that of China, and China's twice that of India. In these Asiatic countries high production is achieved by very intensive cultivation, but with a very low output per man.

Theoretically, it is possible to double the yields per acre in most of the world. According to Robert M. Salter of the U.S. Department of Agriculture, by 1960 pre-war yield could be increased by 25 per cent in the U.S.A., 30 per cent in China and the U.S.S.R., 50 per cent in

India, and 30 per cent for the world as a whole. To attain this, it would be necessary to increase the consumption of phosphate fertilizer eightfold, and that of potash 10 times, in addition to a large increase of nitrogenous fertilizers.

According to FAO, the land now under cultivation totals about 2,400 million acres, or one acre per person, the last figure varying from four acres per head in North America to 0.5 in eastern Asia. A 1,000 million acres of tropical land which could be brought into cultivation would yield 1,200 million tons of food, and another 300 million acres in the Temperate Zone would yield another 120 million tons, thus bringing the total production up to 2,700 million tons—far above the minimum requirement of 1,630 million tons.

But even assuming—which is unlikely—that these goals can be attained, the increased supply of food would be of little help if the world's population continued to increase at the present rate. Adjustment of population to resources is necessary. Indeed, this is by far the largest part of the problem.

There is also the remote possibility of converting coal, limestone and air into food; but food production must be based upon renewable resources, and the use of coal for this purpose could be only a temporary expedient. A more rational solution would be that provided by wood. Of the 12,000 million acres of the world which were at one time covered by forests, there still remain 8,000 million acres, 5,000 million of which are virgin forest. These 8,000 million acres could yield annually 8,000 million tons of wood, the conversion of which into fuel, power, housing, fibres and food would permit a high standard of living. It might be possible to develop more economical methods than those used during the war in Sweden and Germany for converting wood into sugar, alcohol and cellulose food. In any case, reafforestation is essential not only for providing wood products, but for soil conservation and flood control.

However, food resources are not limited to the land. The oceans are more productive per acre than the land. But harvesting of plankton would not yield anything like economic returns, and fish production accounts for some 2 per cent only of the world's food production.

In fact, the problem of food resources must be considered in relation to population density, distribution and economic development. Only Western Europe, North America and Oceania have made the transition from a high-birth, high-death-rate culture with low living standards to a low-birth, low-death-rate culture with high living standards. The U.S.S.R., the Balkans, Argentina, South Africa and Japan are just beginning the demographic transition. But it is the third group—southern and eastern Asia, South and Central America, and Africa—which are the real problem. This group contains 60 per cent of the world's population with an average annual income of less than a tenth of that of group 1. Birth control would seem to be the only solution for this group of peoples, but people who live at subsistence levels do not adopt birth control techniques, not even in the West. Assuming that food production could be increased in Asia and that this area could make the demographic transition, it is most unlikely that it could do so with less than a threefold increase in population—from

over 1,000 million to more than 3,000 million. But Asia cannot support a population of 3,000 million on known available resources.

Yet the biological resources of the world are adequate to provide reasonable living conditions for all if the demographic transition is made rapidly. But it cannot be done if there is war or threat of war. If the world can return to peace, the rehabilitation programme should be started with the nations that have already begun their demographic transition. To try to do more would be too great a drain on the 20 per cent of the world's people who have made the transition, and an inadequate effort would be worse than no programme at all. As the nations of this second group reach demographic and economic maturity, they would join the modern Western nations in a programme for rehabilitating the undeveloped areas, and so on. An inadequate programme can only intensify the problem and make any real solution more difficult. It is futile to introduce public health measures to prevent people dying from diseases if they are only to die of starvation. There is no merit in increasing food production if the only effect is a larger population living at subsistence levels. Public health, improved agriculture, industrialization and education are all essential, but they must be developed simultaneously if they are to be effective.

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